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THESIS

NUMERICAL ANALYSIS OF THE ELASTIC SHOCK RESPONSE
OF SUBMARINE INSTALLED EQUIPMENT

by

Mark Steven Welch

September 1984

Thesis Advisor: Y. S. Shin

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A152564	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* Numerical Analysis of the Elastic Shock Response of Submarine Installed Equipment		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1984
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR*(s)* Mark Steven Welch		8. CONTRACT OR GRANT NUMBER*(s)*
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE September 1984
		13. NUMBER OF PAGES 114
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

DDAM, ELSHOK, Finite Element, Finite Difference, Modal Analysis, Elastic Shock Response, Submarine Shock, Submarine-Installed Equipment.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Motivated by a lack of explosive test data on nuclear submarines, the Navy has sought other means to qualify installed equipment in submarine shock environments. The currently used method for non-shock testable items is the Dynamic Design Analysis Method (DDAM) developed by the Naval Research Laboratory in the early 1960's. With the advent of large-scale computing power, newer numerical methods have become

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response code. The limitations and strong points of both methods are
examined using illustrative examples.

Numerical Analysis of the Elastic Shock Response
of Submarine Installed Equipment

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September, 1984

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ABSTRACT

Motivated by a lack of explosive test data on nuclear submarines, the Navy has sought other means to qualify installed equipment in submarine shock environments. The currently used method for non-shock testable items is the Dynamic Design Analysis Method (DDAM) developed by the Naval Research Laboratory in the early 1960's. With the advent of large-scale computing power, newer numerical methods have become available to predict equipment responses. This investigation is a comparative study of DDAM and ELSHOK; a new generation numerical shock response code. The limitations and strong points of both methods are examined using illustrative examples.

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I. INTRODUCTION

A. BACKGROUND

Modern combat vessels must be designed with the
capability to survive moderately severe shock loadings
induced by the underwater explosion of conventional or
nuclear weapons. In the scope of this investigation,
survival includes the mission survival of the platform. It
must maintain its ability to utilize all machinery and
weapons systems to carry out its primary mission following
an underwater explosive attack. Although the vessel may
withstand considerable hull damage and maintain its
structural integrity, failure of internal equipment can
render it useless as a weapon and thereby eliminate its
value in time of crisis. This investigation examines the
shock loading of internal equipment in submarines and some
of the methods available to analyse shock response.

In view of the fact that a submarine can not be
expected to survive a direct hit by any modern,
high-intensity weapon, many attempts have been made to
specify a level of shock loading for the purpose of design
evaluation. The current specifications for building
submarines contain the shock requirements to be met by the

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builders and vendors of installed equipment. Generally, all equipment is to pass a series of shock tests, in the installed configuration as outlined by MIL-S-901C [Ref.1], where shock testing is practical. This document specifies standard explosive and mechanical test fixtures and procedures for conducting the tests. The suitability of an equipment design or installation is evaluated according to its ability to function as intended during and after each shock impulse. Equipment testing is very expensive and requires a great deal of preparation. In the case of equipment design, it is often not practical to evaluate an installation prior to the final design. In some instances, the direct testing of installed components may not be possible from the aspect of prohibitive size or weight. In these cases, a design analysis is specified.

The design analysis for shock response was first proposed in the United States during World War II. Hull damage reports indicated the degree of suceptibility of installed equipment to shock loadings from bombs and depth charges. Based on limited testing and observations, a shock design factor was specified. A series of curves were used to depict the variation of shock design factor with equipment weight to yield an equivalent static design force. This force was used to specify mounting hardware and main structural members for the equipment installation

and varied with motion input direction. The method proved
to be simple in application but reflected a lack of realism
with experimental tests.

In the late 1950's, nuclear power plants were
incorporated into submarine designs to afford them greater
independence from the frequent surfacing requirements
inherent in conventional submarine operations. Nuclear
power plant technology was new and thus had no previous
history of shock resistance. The acquisition cost of
nuclear components is high and the new dangers associated
with their damage from underwater explosion sparked a
renewed interest in underwater explosion testing and design
analysis. From the late 1950's through the middle 1960's,
most of the currently used standards for submarine-
installed equipment shock design were adopted.

The Dynamic Design Analysis Method (DDAM) was proposed
by the Naval Research Laboratory and accepted by the Navy
as a design evaluation requirement in 1963 [Ref 2]. The
details of this specification will be discussed more fully
later; however, the basic principle is stated here. DDAM is
a simplified modal analysis method which utilizes shock
inputs which were empirically derived from underwater
explosion tests of realistic ship and submarine instal-
lations. It is assumed that the equipment and its foun
dation together make up a system which responds as a linear
elastic structure to the input which is described by a

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design shock spectrum. The successful utilization of DDAM
to evaluate equipment response to a design shock input is
dependent on the ability of the design shock spectrum to
reflect accurately the structural environment existing in a
given installation. This will be influenced by the size
and weight of the submarine test subject, the structural
system employed in the construction of the submarine, and
the interaction between the equipment, foundation and hull
structure used to derive the design shock spectrum.

B.   THE STATE OF CURRENT SHOCK DESIGN ANALYSIS

Since its adoption, DDAM has been used without
modification to qualify ship and submarine equipment
installation designs. The original design shock spectrum
[Ref. 2] remains intact without revision. Shortly after
the adoption of DDAM as a design requirement, underwater
explosive testing of nuclear submarines was banned due to
the inherent risks involved. This ban was relaxed in 1983
for the low level explosive test of a SSN 688 class
submarine. Mechanical and explosive tests of equipment
installations on shock simulation platforms are the only
regular check of designs meeting the standards imposed by
DDAM. A danger exists with this kind of verification in
that the tests may be designed to accurately reproduce the
input motions provided for in the design shock spectrum
utilized with DDAM.

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In recent years the increasing availability of large
computers and the rapid development of numerical methods
have provided the engineer with new tools to use in the
analysis of submarine shock response problems.
Finite-Element/Finite-Difference methods allow for the
analysis of structure and fluid responses and the work of
Geers [Ref. 3] provides a means to incorporate fluid-
structure interaction effects. Several computer codes have
been developed to analyze installed equipment response to
shock waves based on these formulations. One of them is the
Elastic Shock (ELSHOK) code developed by Weidlinger
Associates under Defense Nuclear Agency and Office of Naval
Research funding [Ref.4]. The motivation for this work has
been to investigate modern submarine underwater explosive
shock response in conjunction with a testing program using
small to large scale models and shaped, explosive, tapered
charges. Throughout its development, ELSHOK has been
validated using these highly controlled tests. In the low
level explosive test of the SSN 688 class submarine, ELSHOK
was used to predict the level of equipment responses prior
to the tests and to increase the level of confidence
associated with the tests. This code has now been made
available to the Naval Postgraduate School by the Defense
Nuclear Agency along with support from Weidlinger Associates.

C. PURPOSE FOR THIS INVESTIGATION

DDAM is a design tool. Its function is to provide a numerical method by which the engineer can check his design as to its adequacy for installation in a submarine. It is intended to be conservative and straightforward to apply. When DDAM was first proposed [Ref.4], its authors warned that the design shock factors specified [Ref.2] were not absolutely determined and should be reviewed as explosive testing progressed and data was accumulated. Although testing procedures for installed equipment components have become very sophisticated, these simulators may not accurately reflect the response of installations in modern day submarines. Without the ability to carry out high-intensity shock tests on real submarines, verification of the design shock spectrum used in DDAM can not be accomplished as intended. The evolution of numerical codes capable of simulating the response of installed equipment to a specified shock loading makes available a means to check the applicability of the originally proposed design shock factors provided in DDAM to modern submarines. There is no flexibility built into DDAM to allow design for other than the originally prescribed shock input magnitude. DDAM makes no separate account for equipment/structure interaction effects.

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The purpose of this investigation is to examine the response of several equipment models installed in a present day scale, 6900 long ton (LT) submarine using DDAM and ELSHOK. The equipment models range in weight from 1,000-20,000 pounds. Simple models are used to make correlations possible between the two methods and worst case results are obtained. Additionally, equipment/hull interactions are investigated for their possible influence on overall equipment response.

II. DYNAMIC DESIGN ANALYSIS METHOD

A. DESCRIPTION OF DDAM

As mentioned in the introduction, DDAM is a simplified modal analysis method which utilizes shock inputs which were empirically derived from underwater explosion tests of realistic ship and submarine installations. Although the analysis is identical for both types of vessels, all references in this document will be to submarines. In order to utilize DDAM to evaluate a design, several assumptions must be satisfied.

1.) The equipment and foundation make up a linearly elastic system.

2.) The structure can be represented reasonably well using a lumped parameter model.

3.) The structure is hard mounted to the rest of the submarine. No bottoming, or damped mounts are allowed.

In Navy shock requirements, equipment shock classifications are based on a graded system. These grades run from A for mission critical items, to C for items that could indirectly affect the ability of the vessel to function as intended. For instance, a locker which becomes

adrift and could injure personnel or surrounding equipment could be grade C. The grade of the item is specified by contract and determines the degree of shock qualification it must undergo to be considered safe for installation. In this study, all equipment models were considered grade A.

The ideal way to compute the elastic shock response of an installed equipment is to consider the entire structure (submarine and equipment) as an elastic system. The normal modes and natural frequencies of this system can then be determined and the response of each normal mode to the water applied pressure loadings computed. The modal responses can then be superimposed to get the resultant equipment response. In an everyday design method such as DDAM, this approach is impractical. To simplify the above procedure, DDAM utilizes the concept of a shock spectrum. Any point on the complete structure can be designated as a reference point which can then be considered to be a fixed base for the equipment on one side of it. The dynamic response of this portion can then be computed by superposition of normal mode responses to the motion of the fixed base. In DDAM, this motion is specified as a step input to each normal mode and is calculated by empirical equations based on underwater explosion tests of models and submarines [Ref. 5]. A detailed treatment of the mathematical basis for DDAM is given by Butt [Ref. 6].

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In order to use DDAM, a lumped parameter model of the
equipment must be formulated to obtain the matrix
expression:

$$[M] \{\ddot{X}\} + [K] \{X\} = \{0\} \qquad (1)$$

which has the associated eigenvalue problem

$$[M] [X_{ia}] [\omega^2] = [K] [X_{ia}] \qquad (2)$$

where $[X_{ia}]$ is the matrix of eigenvectors and $[\omega^2]$ is the
diagonal matrix of natural frequencies. The advantage of
this procedure is that it allows uncoupling of the
equations of motion and subsequent solution of the dynamic
problem in terms of its component modes. Careful
formulation of the equations of motion to capture all the
dominant characteristics of the equipment leads to good
results with only a small number of modes. When DDAM was
developed, it was intended to be used primarily in hand
computations. The major difficulty encountered in the use
of DDAM was the solution of the eigenvalue problem which
can readily be handled today with small computers. The
normal mode theory upon which DDAM is based is well
established in shock and vibration practice. The area of
concern is the adequacy of the adopted design inputs to
reflect present day submarine building practices.

B. DESIGN SHOCK INPUTS

The specification of design shock inputs for use in
DDAM calculations determines the usefulness of this method

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in the evaluation of equipment installation designs. DDAM
is a standard. The design input values must provide
consistent fixed-based equipment excitations for the broad
base of submarine platforms in use today to simulate a
"standard" underwater explosion. To simulate this require-
ment here, charge weights and standoffs were selected so that
each case corresponded to a constant value of energy flux
density; i.e.,

$$W/R^2 = \text{Constant} \qquad (3)$$

In this equation, W is the equivalent weight of the charge
in pounds of TNT and R is the standoff distance from the
hull in feet. The submarine platforms in use today range in
size from about 4,600-18,700 LT. Each submarine hull is
characterized by its own modal properties (mass distri-
bution, natural frequencies, mode shapes). The same piece
of equipment as is installed in a small submarine will
demonstrate a different response when installed in the same
configuration, in a large submarine. The effect of hull/
equipment interaction becomes an important consideration in
large pieces of equipment tuned to one or more natural fre-
quencies of the hull structure. The design shock input used
with DDAM must incorporate these factors so that when it is
said that a piece of equipment meets the specification for
qualification, the qualification level is the same for all
submarine classes.

In the publications regarding DDAM, little is said about the origins of the particular shock input spectrum utilized to evaluate equipment response. It has been empirically derived to provide values consistent with the data upon which it is based. In the event that it is decided to design submarines to resist underwater explosions of a different shock intensity than the one chosen for the present method, a major effort would be required to construct a data base upon which to base the new input values.

C. USING DDAM

Since the development of DDAM, new tools have replaced the slide rules of engineers. Among them are the readily available desktop computers. In the course of this work, it was necessary to use DDAM to analyse simple structures of fewer than 50 degrees of freedom. To this end, a computer program has been written in the BASIC computer language to carry out the required computations. A listing and short users' manual can be found in Appendix A. The program was verified by comparing results with hand calculations and published sample problems.

III.   EXPLOSIVE SHOCK RESPONSE ANALYSIS USING ELSHOK

A.   GENERAL PRINCIPLES OF OPERATION

The ELSHOK computer code [Ref. 4] calculates the
transient response of a submerged, ring-stiffened shell of
revolution, with or without internal structure, to an
underwater shock wave emanating from an explosive source
placed at an arbitrary location away from the shell. The
structure is considered to be linearly elastic, and the
surrounding fluid is treated as an infinite acoustic
medium. Modal structural analysis is used in all phases of
the calculations. Internal equipment response is treated
by coupling the free-free modes of the empty ring-stiffened
shell and the fixed-base modes of the internal equipment
through use of dynamic boundary conditions [Refs. 7,8].
The structure-fluid interaction is approximated by means of
the Doubly Asymptotic Approximation (DAA) due to Geers
[Ref. 3]. The form of the DAA used is that obtained when
the normal fluid displacement of the structure-fluid
interface is expanded using surface expansion functions
which are orthogonal over the wet surface of the submarine.
At frequencies of zero and infinity, the pressure-velocity
relations are exact so that in transient analysis, the DAA
yields exact results at early and late times, and by the

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nature of its formulation provides a smooth transition
between these two limits. In effect, the DAA allows for
uncoupling of the fluid field problem from the structural
field problem.

The structural problem solved by ELSHOK is separated
into two parts. A modal substructuring procedure is used to
solve the dynamic response problem for internal equipment.
The advantage of this is to eliminate the need to handle the
modes and natural frequencies of the combined structural
problem, as well as the requirement for a combined system
stiffness matrix. Interaction forces and moments, and
compatibility of deformation at the shell-substructure
attachment points are used to solve for the dynamic response
of the component parts.

Referring to the ideal case of DDAM formulated without
the use of a shock input value; ELSHOK is a numerical means
to arrive at the input to the substructure without depend-
ence on an explosive testing database and with the added
advantage that interaction effects between the hull and
substructure are taken into account. ELSHOK performs a
transient analysis whereas DDAM utilizes a simplified
"front end" to arrive at the maximum forces and deflections
in a given response problem for a single magnitude of
loading.

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B.   ORGANIZATION AND IMPLEMENTATION OF ELSHOK

The ELSHOK code is implemented as a series of seven programs. The major components are:

1.   BOSOR4   - structural analyzer for shell [Ref. 9]

2.   ACESNID - virtual mass processor

3.   PIFLASH - shell-fluid processor

4.   SAPIV   - structural analyzer for substructure
                [Ref. 10]

5.   PICRUST - substructure processor

6.   USLOB   - time integration processor

7.   PUSLOB - plotting processor

Figure 1 depicts the general relationship among the code modules. The numbers above correspond to the chronological execution order to be followed in a given analysis. In order to carry out an analysis using ELSHOK, a lumped parameter model of the submarine being analyzed must be formulated or available as well as the equipment model. More will be said about models later. The computations are carried out in four phases.

B.1.   Phase I - Shell and Fluid Analysis

BOSOR4 is a finite difference code used to capture the effects of the submarine hull structure on the overall response. Two models are actually used: a full model containing information about the major configuration

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PHASE II

REPEAT PHASE II FOR EACH SUBSTRUCTURE.

SKIP TO PHASE III IF THERE ARE NO SUBSTRUCTURES.

MODAL ANALYSIS OF SUBSTRUCTURE
SAP IV

SUBSTRUCTURE PROCESSOR
PICRUST

PHASE III

PHASE IV

MODAL ANALYSIS OF SHELL
BOSOR4

VIRTUAL MASS PROCESSOR
ACESNID

SHELL-FLUID PROCESSOR
PIFLASH

MERGE DATA FILES

TIME INTEGRATION PROCESSOR
USLOB

PLOTTING PROCESSOR
PUSLOB

PHASE I

Figure 1 - Organization of the ELSHOK Computer Code [Ref.4]

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of the submarine and its general dynamic properties, and a compartment model representing the localized area of interest on the hull. The full model is used to capture the gross effects of the response such as rigid body translation and whipping ($N = 1$ modes), and rolling and twisting ($N = 0$ torsional modes) of the entire structure. The compartment model is used to capture local details of the response in the area of interest ($N = 0$ breathing and $N \geq 2$ modes). N is the integral number of circumferential waves or harmonics in the circumferential distributions of the surface expansion functions. For each N, a separate BOSOR4 calculation is required. The BOSOR4 code provides the in-vacuo free-free modes and natural frequencies of the submarine hull.

The second part of phase I is the use of ACESNID to compute the virtual mass array, which is used in the late time contribution of the DAA. The virtual mass array is determined from the solution, based on simple sources, of a steady-state low frequency problem in which normal displacements corresponding to the surface expansion functions are applied to the surface of a cavity of revolution in an infinite fluid having the same size and shape as the wet surface of the submarine. Only one run of this module is required for all values of N considered.

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The final step in phase I is the execution of PIFLASH to compile the data from all BOSOR4 runs and ACESNID into a shell-and-fluid file for later use. The analysis done for the work in this thesis considered only the hull response of one submarine so only one shell-and-fluid file was needed for all subsequent calculations.

B.2   Phase II - Substructure Analysis

SAPIV is a commonly available finite element code used in the ELSHOK code to perform the modal analysis of each substructure (equipment model). The equipment installation is first cast into an appropriate finite element representation and then SAPIV is used to solve for the desired mode shapes and frequencies. This information is placed in a substructure mode file along with the geometry, stiffness and mass information. The mass, mode, and frequency information were also used in the DDAM analysis for comparative purposes.

The final step in phase II is the execution of the PICRUST code. This code prepares the input for phase III calculations by placing the above modal information on a substructure file. Additionally, it calculates influence coefficients corresponding to the base or support motions of the substructure and accounts for the user-specified connectivity.

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B.3. Phase III - Time Integration

Following the completion of Phases I and II, the shell-and-fluid file is merged with the substructure file to form the input file for USLOB which is ELSHOK's time integration processor. USLOB allows specification of the charge weight and geometry. For the problems of concern here, an exponentially decaying, empirical model was used to represent the explosive shock source. It is of the form:

$$P_I(R) = K_1 (W^{1/3}/R)^{K_2} \exp(-t/\theta_0) \qquad (4)$$

where;

$P_I(R)$ = the incident pressure at a radius R from the explosion (on the hull)

K_1 = a multiplicative constant for incident pressure

K_2 = a spatial decay constant for incident pressure

t = time after arrival of shock wave at point of interest

W = weight of spherical charge

θ_0 = $K_3 W^{1/3} (W^{1/3} / R)^{K_4}$

K_3 = multiplicative constant for time constant of exponential decay

K_4 = spatial decay constant for time constant of exponential decay

In all the cases, the geometry was such as to maintain constant energy flux according to eq.(3). The integration in time is done using a modified version of the Runge-Kutta

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numerical integration scheme. During the integration,
USLOB outputs velocity histories for user-specified points
on the hull and substructure.

B.4. PhaseIV - Plotting

Phase IV capabilities were not utilized in this investigation. However, ELSHOK does have the capability to generate plot files containing velocity history information for processing on a graphics terminal.

B.5. Deflection Calculations

As mentioned previously, ELSHOK produces velocity histories at the points of interest on the substructure. DDAM produces maximum deflections or forces at the same points for similar models. In order to make comparisons between the two methods, it was decided to convert the velocity histories from ELSHOK to deflection histories using an integrator based on Simpson's 1/3 Rule. For each equipment case, a separate program was written in BASIC to accomodate the variations in configuration between each model and the differences in output from the USLOB code due to point of interest specification. These programs are listed in Appendix B.

IV. MODELS USED IN THE ANALYSIS

A. FINITE ELEMENT/FINITE DIFFERENCE MODELS

The idea of representing a given domain as a collection of discrete elements or values was not first applied in finite element/finite difference methods. Early mathematicians estimated the value of π to nearly 40 decimal places by representing the circle with a polygon of a finitely large number of sides. The polygon used by the mathematicians is a model of the circle they wished to represent. In modern numerical methods, it is realized that very few problems in the real world can be analyzed without the use of simplifying models. BOSOR4, the finite difference code in ELSHOK used to describe the dynamic behavior of the submarine hull, requires a greatly simplified model of its real world counterpart. Similarly, both DDAM and ELSHOK use a substructure model to capture the fixed-base properties of installed equipment.

B. SUBMARINE HULL MODELING USING BOSOR4

Actual submarine hulls are very complex structures. However, they do possess certain characteristics that can be used to simplify their modeling. From the aspect of submarine hull shock response, the hull is a free-free ring stiffened cylinder with suitable end closures. The

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internal weights of machinery and other outfitting must be accounted for but these items can be smeared into their adjacent hull structure. The model thus becomes a cylinder whose cross sections reflect the density of the submarine at a given frame. Since a cylinder is a surface of revolution, the properties of each cross section need only be specified at one point. The reader will notice that any hard structure serving to stiffen the hull in a non-axisymmetric sense, such as non-circular frames or massive machinery foundations, can not be represented in this fashion. If these structures are in the area of interest in the hull, they should be modeled as internal structures in phase II of ELSHOK.

The BOSOR4 code allows the submarine hull model to be constructed by specifying the properties of the submarine hull along a line of revolution. A numerical complication enters the problem when dealing with models of submarines because the structure often repeats itself regularly along its axis of revolution. With such a configuration, there are many modes in which the motion of the stiffeners is of small amplitude compared to that of the shell. The bays between the rings vibrate at frequencies which may approximate those corresponding to a simply-supported cylinder of the same geometry as the bay. Multiple or closely-spaced eigenvalues correspond to modes in which

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one or more of the bays is vibrating while others are

unaffected. To avoid eigenvalue difficulties, the prudent

measure is to analyse as small a segment of shell as

possible in order to avoid numerical difficulties with

multiple, or closely-spaced eigenvalues as indicated by

Bushnell [Ref. 9]. In submarine shock analysis, the

interest is in the gross response contributions of the

entire hull to a given section of interest. The authors of

ELSHOK have allowed for this through the use of two models.

A full model is used to obtain the gross contributions

of the entire hull structure in the $N = 0$(torsional) and

$N = 1$ (translational and whipping) modes. This will include

such things as bulkheads, heavy ring stiffeners, and end

closures. A compartment model is then used to obtain more

detailed information about the particular section of

interest. In this way, responses away from the section of

interest do not have to be carried through the remaining

calculations since they do not affect the response of this

area anyway.

Due to security restrictions placed in information re-

garding the construction techniques and arrangements of U.S.

nuclear submarines, it was not possible to model an actual

submarine for use in the analysis work contained in this

thesis. With the aid of Weidlinger Associates of New York,

however, a model resembling a general submarine hull struc-

ture of 6900 long tons displacement was obtained. This

model is available through the U.S. Naval Postgraduate
School but is not included here so that restrictions do not
have to be placed on the circulation of this work.

Figure 2 is a schematic depiction of the full subma-
rine. The submarine being modeled has been cut into 149
slices along the longitudinal axis. In the model, _infor-_
mation regarding Young's modulus, Poisson's ratio, mass
density, thermal expansion coefficient, plating half-
thickness and whether or not stiffeners are smeared is pro-
vided for each one of these points. Twenty-six discrete
rings are represented along the axis of the model, twenty
of which are in the local area of interest. These rings
represent frames in the real submarine where T-stiffeners
give increased stiffness to the hull. In actuality, these
stiffeners are spaced fairly evenly along the entire model,
but smearing them outside the area of interest will not
appreciably affect the vibrational characteristics in the
area of interest. Using the BOSOR4 code, modal analysis
using finite difference techniques is carried out. Table
1 is a listing of the natural frequencies and wave numbers
for each mode retained in the analysis. Seven N = 0
torsional modes, and thirty-eight N = 1 rigid body
displacement and whipping modes have been retained for the
full model.

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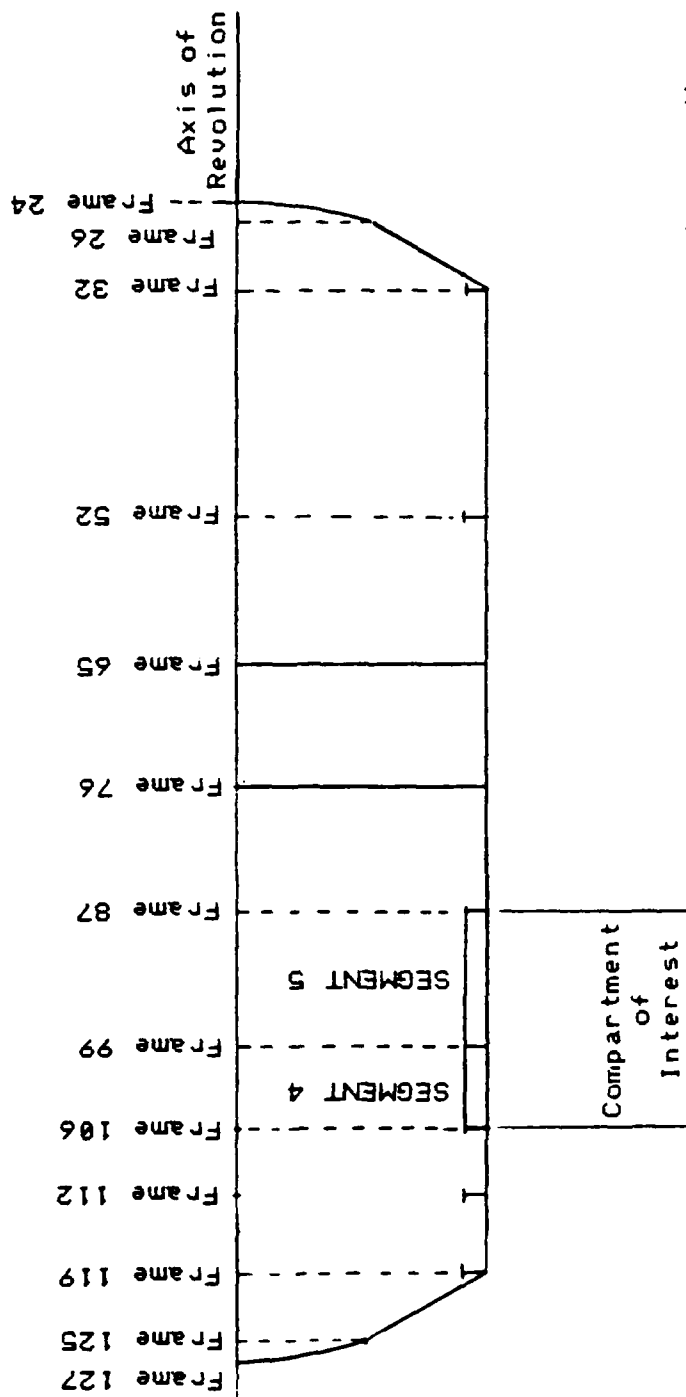
Note: compartment of interest details are the same as depicted in figure 3.

Figure 2 - Full Model Used to Capture Gross Response of Submarine

MODE	N	FREQ (Hz)	MODE	N	FREQ (Hz)
1	1	3.597568E-02	2	1	4.716345E-02
3	1	2.877285E+00	4	1	7.890112E+00
5	1	1.298816E+01	6	1	1.793631E+01
7	1	1.801155E+01	8	1	1.897726E+01
9	1	2.305725E+01	10	1	2.720918E+01
11	1	2.992269E+01	12	1	3.228725E+01
13	1	3.411510E+01	14	1	3.498256E+01
15	1	3.568254E+01	16	1	3.590094E+01
17	1	3.716095E+01	18	1	3.806356E+01
19	1	3.847244E+01	20	1	3.962965E+01
21	1	4.027563E+01	22	1	4.059142E+01
23	1	4.295875E+01	24	1	4.390227E+01
25	1	4.492591E+01	26	1	4.916127E+01
27	1	5.261150E+01	28	1	5.289662E+01
29	1	5.544796E+01	30	1	5.634701E+01
31	1	5.994869E+01	32	1	6.131432E+01
33	1	6.312191E+01	34	1	6.521966E+01
35	1	6.574109E+01	36	1	6.682896E+01
37	1	6.761096E+01	38	1	6.845927E+01
39	0	4.013475E-05	40	0	7.584749E+00
41	0	1.465699E+01	42	0	2.342790E+01
43	0	3.021683E+01	44	0	3.855958E+01
45	0	4.579604E+01			

TABLE I - Wave Numbers and Frequencies of Full Model

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Figure 3 is a schematic representation of the compart-
ment (local area of interest) model used in this analysis.
In this model, all frames are modeled as discrete ring
stiffeners. Since compatibility must be maintained between
the two models, (compartment and full), there is a one to
one correspondence in the area of interest between points
in each model. The compartment model is used to obtain the
modal contributions corresponding to N ≥ 2 (normal, merid-
ional, and circumferential displacements). As mentioned
previously, deformations or motions occuring beyond the
region of interest should be unimportant for the N = 0
breathing modes and modes corresponding to N ≥ 2. Each
bounding ring or bulkhead is very stiff in its own plane
and moves primarily in that plane for localized loading.
Table 2 is a listing of the natural frequencies and
circumferential wave numbers for each mode retained in the
analysis. For the compartment model, 25 modes corres-
ponding to N = 2, 24 modes corresponding to N = 3, 24 modes
corresponding to N = 4 and 25 modes corresponding to N = 0
have been retained. A total of 254 modes were found by
BOSOR4 for the full and compartment models. Of these
modes, 143 were retained for further calculations in phase
II and III of ELSHOK. The 111 modes that were dropped
affect responses primarily outside of the area of interest.
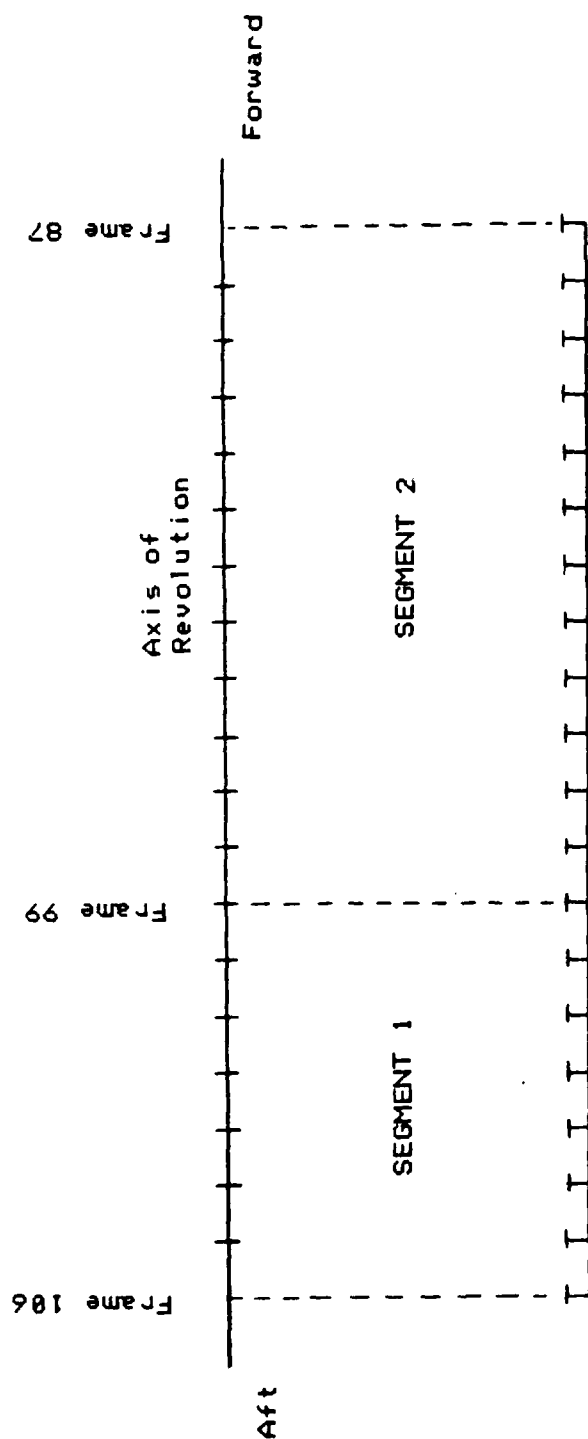
Figure 3 – Compartment Model Depicting Area of Interest
(Note: all major stiffeners included)

MODE	N	FREQ (cps)	MODE	N	FREQ (cps)
1	2	7.468789E+00	2	2	8.734529E+00
3	2	2.348234E+01	4	2	3.479523E+01
5	2	3.630018E+01	6	2	3.915876E+01
7	2	4.866827E+01	8	2	5.391393E+01
9	2	5.852534E+01	10	2	6.621577E+01
11	2	7.125992E+01	12	2	7.284292E+01
13	2	7.573407E+01	14	2	7.843223E+01
15	2	7.850576E+01	16	2	8.092760E+01
17	2	8.341864E+01	18	2	8.354483E+01
19	2	8.646392E+01	20	2	8.778771E+01
21	2	8.896759E+01	22	2	8.989995E+01
23	2	9.272942E+01	24	2	9.475832E+01
25	2	1.007987E+02	26	2	1.813456E+02
27	2	2.555379E+01	28	3	3.864289E+01
29	3	3.538415E+01	30	3	3.965320E+01
31	3	4.383660E+01	32	3	4.571721E+01
33	3	4.761181E+01	34	3	4.934542E+01
35	3	5.352091E+01	36	3	5.896834E+01
37	3	6.117877E+01	38	3	6.686933E+01
39	3	6.961758E+01	40	3	7.115673E+01
41	3	7.465009E+01	42	3	7.683416E+01
43	3	7.795620E+01	44	3	8.125859E+01
45	3	8.312995E+01	46	3	8.451348E+01
47	3	8.721984E+01	48	3	8.895788E+01
49	3	9.991350E+01	50	4	2.483686E+01

MODE	N	FREQ (cps)	MODE	N	FREQ (cps)
51	4	3.166806E+01	52	4	3.371339E+01
53	4	4.384663E+01	54	4	4.852398E+01
55	4	5.246322E+01	56	4	5.753878E+01
57	4	5.839672E+01	58	4	5.996636E+01
59	4	6.132389E+01	60	4	6.295984E+01
61	4	6.489963E+01	62	4	6.722555E+01
63	4	6.812710E+01	64	4	6.924025E+01
65	4	7.073226E+01	66	4	7.251855E+01
67	4	7.376491E+01	68	4	7.659343E+01
69	4	7.834125E+01	70	4	7.971665E+01
71	4	8.213363E+01	72	4	8.386734E+01
73	4	9.928959E+01	74	8	1.334394E-04
75	8	2.776871E+01	76	8	2.999275E+01
77	8	7.198928E+01	78	8	8.395790E+01
79	8	8.434925E+01	80	8	8.450424E+01
81	8	8.493266E+01	82	8	8.531557E+01
83	8	8.574835E+01	84	8	8.648527E+01
85	8	8.663983E+01	86	8	8.724835E+01
87	8	8.797867E+01	88	8	8.884455E+01
89	8	8.972277E+01	90	8	9.051744E+01
91	8	9.198160E+01	92	8	9.246087E+01
93	8	9.479385E+01	94	8	9.587931E+01
95	8	9.559086E+01	96	8	9.873169E+01
97	8	1.012882E+02	98	8	1.027781E+02

TABLE II - Wave Numbers and Frequencies of Compartment Model

Figure 4 is a schematic of the general shell structure model and notation conventions used in the remainder of the ELSHOK analysis. Two coordinate systems are used. X,Y and Z refer to the submarine global coordinate frame and x,y and z refer to the substructure local coordinate frame. In both systems, the x-axes run from aft to forward and the z-axis orientation is related to the Z axis in the global system by the angle α_σ where σ refers to the substructure. The variable s is used to locate points along the meridian of the full model, and u,v, and w are used for local shell displacements and motions located circumferentially by the angle θ. This concludes the discussion of the submarine model used in ELSHOK.

One of the conveniences realized in using a DDAM analysis to carry out design checks is the absence of a submarine model in the computations. The design shock values are intended to provide all inputs to the substructure model. The penalty which must be weighed here is the lack of regard which this places on the peculiarities of a given submarine structure. On the other hand, the ELSHOK submarine model is difficult to construct requiring a great deal of information and skill to properly model a given hull, but the price is paid only once for each submarine class. All subsequent calculations in this thesis are carried out utilizing the same shell model calculations.

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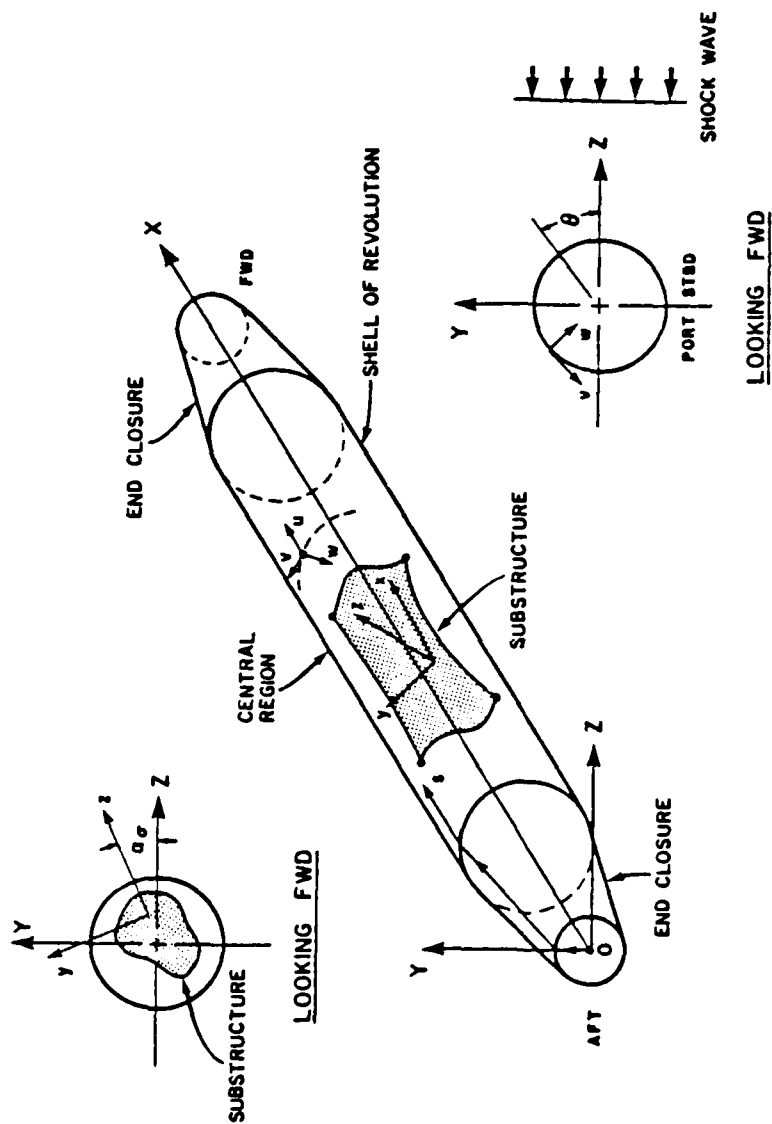
Figure 4 - Shell-Substructure Configuration [Ref. 4]

C. SUBSTRUCTURE MODELING USING SAPIV

In both DDAM and ELSHOK calculations, a substructure model is formulated to determine the modes, masses, and natural frequencies of the equipment system being design checked. When DDAM was first developed, a computer program was available which could solve the eigenvalue problem for up to twenty degrees of freedom. However, the scarcity of computer resources dictated that most users utilize hand computations for this purpose. Consequently, most early design checks were limited in scope. DDAM is well suited to tabular methods of computation but with the common availability of small computers today, hand computations are no longer required, and the restrictions on degrees of freedom are largely removed. This is not to say that great numbers of degrees of freedom are required in every case. By careful examination of the equipment installation being checked, the major response contributions can be captured using a small number of modes. In the cases considered in this thesis, emphasis was placed on using equivalent models for DDAM and ELSHOK rather than closely modeling a real component in a submarine as it would be in each case in actual practice. The interest here lies in how the results compare, for the same models.

Phase II of ELSHOK utilizes the SAPIV finite element code to model submarine-installed equipment. Because

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ELSHOK is written utilizing program modules which execute independently and exchange data through output files, the SAPIV code could be used to run the modal analysis of equipment models for DDAM and ELSHOK thus ensuring equivalence in input to both methods. The models selected for analysis were kept small so that comparisons could be made without excessive complication.

Three equipment models have been examined for this thesis. Case I is a cantilever foundation model with a 1000 lb weight attached to its free end. Cases II and III are a simple beam foundation supporting two weights at centerspan and having attachment points on two separate, discretering stiffeners.

C.1. Substructure Case I Model

The case I model development is depicted in figure 5. The model represents a 1000 lb valve supported by a cantilever foundation. The foundation is built up from AISC C 10x30 steel channels [Ref. 11] and the valve is rigidly fixed to the free end. Since the intent was not to qualify any particular valve design, the entire valve has been modeled as a particle (lumped mass). The beam mass is represented by six lumped masses. The foundation is designed to be fixed to a discrete-ring stiffener in the submarine in an upright position. Although 3-dimensional motoion has been allowed, the maximum deflection occurs in the athwartship direction in response to a side-on shock

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loading. This case is representative of a relatively light equipment installation.

C.2. Substructure Case II Model

The case II model development is depicted in figure 6. The model represents a foundation constructed from AISC W 27x177 I-beams [Ref. 11] supporting two 10,000 lb weights. The foundation structure is represented by 18 beam elements and 19 masses. It spans two discrete stiffeners to which its ends are fixed. This model is representative of a large pump or turbomachinery installation.

C.3. Substructure Case III Model

The case III model is similar to the case II model except the foundation structure has been changed to AISC W 27x144 I-beams [Ref. 11] and the supported weights have been reduced to 5,000 lb apiece. This model represents an intermediate weight equipment installation such as a main feed pump.

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AISC C 10X30 Steel Foundation
Properties

I_{xx} = 333.1 in.^{4}
I_{yy} = 206.0 in.^{4}
J = 540.0 in.^{4}

web   thickness = 0.673 in.
flange thickness = 0.436 in.
area of channel = 8.82 in.^{2}
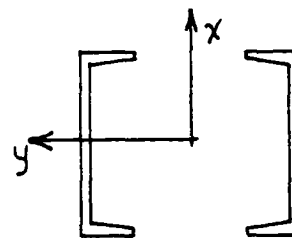
Section A-A
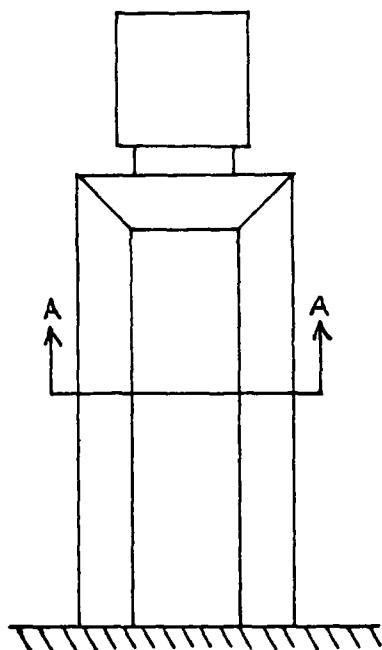
REAL WORLD FOUNDATION
AND MASS
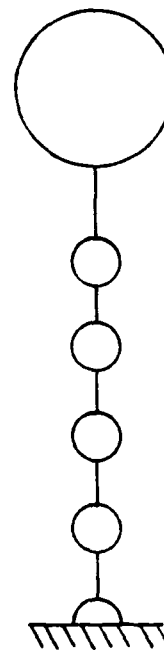
FINITE ELEMENT MODEL
FOR DDAM & ELSHOK

Figure 5 - Case I Equipment and Finite Element Model

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AISC W 27X177 Steel Foundation
Properties
_____

I_{xx} = 6740 in.^{4}
I_{yy} = 556 in.^{4}
J = 20.1 in.^{4}

web   thickness = 0.725 in.
flange thickness = 1.190 in.
area of beam   = 52.2 in.^{2}

CASE II
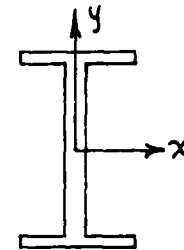
Section A-A

AISC W 27X114 Steel Foundation
Properties
_____

I_{xx} = 4090 in.^{4}
I_{yy} = 159 in.^{4}
J = 7.36 in.^{4}

web   thickness = 0.570 in.
flange thickness = 0.932 in.
area of beam   = 33.6 in.^{2}

CASE III

Section A-A

FR 94

FR 95
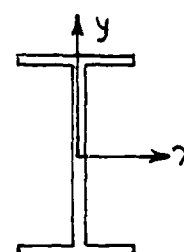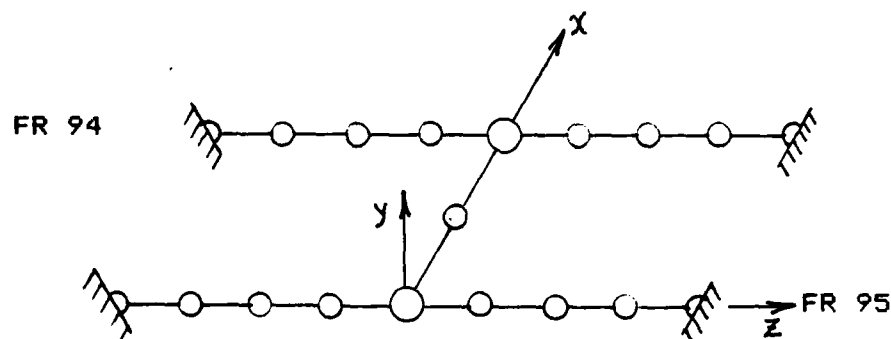
Figure 6 - Case II & III Finite Element Model

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V. ANALYSIS

The goal of the analysis procedure used in this inves-
tigation is two-fold. The primary objective is to analyze
equivalent substructures using DDAM and ELSHOK so a com-
parison of the maximum predicted deflections can be made.
Secondly, any hull/substructure interaction effects are to
be noted. The analysis is complicated by several factors.
All the calculations are based on constant energy flux which
is dependent on charge weight and standoff. Since DDAM
shock inputs ultimately represent the results of explosive
shock tests, the geometry of the "analytical charge" is
invisible to the user and assumed in the empirical shock
spectrum. ELSHOK uses inputs of charge weight and standoff
to calculate shock loading by eq. (4) so the effects of
their variation will change the transient response of the
substructure even though the shock intensity is constant.
In this analysis, three sets of charge weight and standoff
were used. A further complication results due to the fact
that DDAM only can be used to calculate maximum relative
deflections or forces. ELSHOK calculates transient
velocities incurred by the model which must be converted to
maximum relative deflections.

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A. CASE ANALYSIS PROCEDURE

Each case analysis was begun by first constructing the
equipment models to be investigated using SAPIV. A dynamic
analysis was performed to find the natural frequencies and
mode shapes of the model. This information was saved along
with the mass matrix for subsequent DDAM calculations.
Using PICRUST, the SAPIV data was then reduced to a suit-
able form to be merged with the hull structure/fluid data
from Phase I calculations. Finally, all the resulting data
were integrated using the USLOB code to compute the tran-
sient velocity profiles for each equipment installation
configuration and charge weight/standoff set.

The PICRUST code was used to specify the installation
configuration of each model. Model coordinate system orien-
tation to the hull system is determined by the angle α_0 in
fig. (4). The location of the equipment along the longi-
tudinal axis is also specified. For example, in the case I
model, the angle is 270 degrees and the base attachment is
at frame 95 in the submarine model (within the compartment
model). For the case II and III models, two different
orientations were investigated, one with the model mounted
athwartship and the other with the model mounted verti-
cally, i.e., shock input from the side and bottom of the
submarine.

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The USLOB code allows input of charge weight and standoff. To investigate how these parameters affect the transient response of the substructure, three sets of values were used for these parameters based on three different charge weights. The parameters chosen are listed in the following table.

Charge Weight (lbs TNT)	Standoff Distance (Inches/Feet)
5,000	1,414/117.9
10,000	2,000/166.7
15,000	2,450/204.2

TABLE III - Charge Weights and Standoffs for Analysis

After selection of all factors affecting the geometry of the problem, the time step increment and integration limits were specified. In each case, enough time steps were chosen to capture the peak response amplitudes. This number was found by trial and error.

After calculation of the velocity profiles for a given model, this information was integrated using Simpson's 1/3 rule to obtain a deflection history and the maximum deflection response of the model. As alluded to earlier, the models were constructed so that suitable differences taken between the velocity profiles of designated points would yield the relative deflection, at any instant in time, of

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the point in question. This procedure unfortunately re-
lies, to a certain extent, on symmetry in the model. For
instance, in the case I model, the deflection of the weight
on the end of the cantilever in the athwartship direction
can be obtained by integrating the difference between the
velocity histories of the base and the tip of the beam.
Figures (7) and (8) show schematically the differences
taken to calculate deflections for each model configura-
tion.
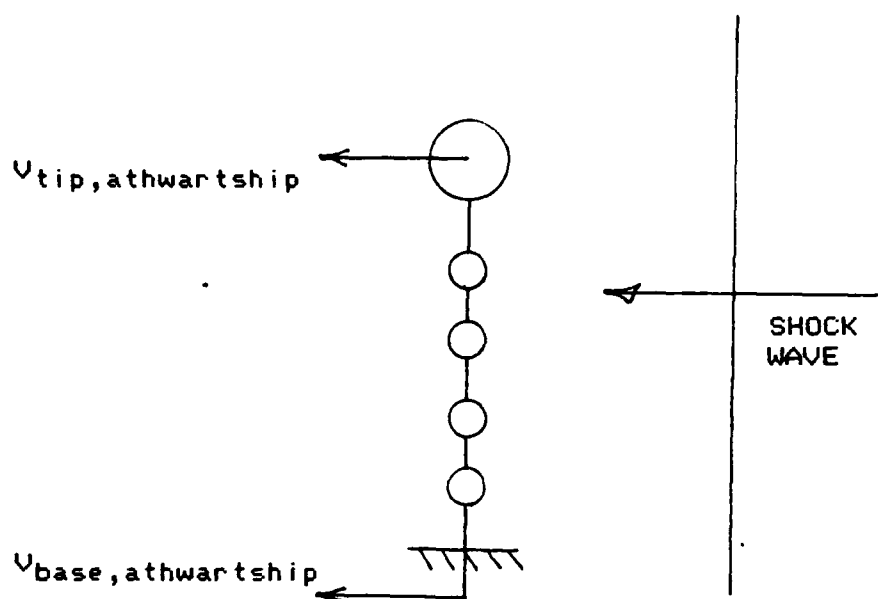
$$V_{rel} = V_{base,athwartship} - V_{tip,athwartship}$$

Figure 7 - Relative Velocities Used to Calculate
          Relative Deflection Between Mass and
          Base for Case I
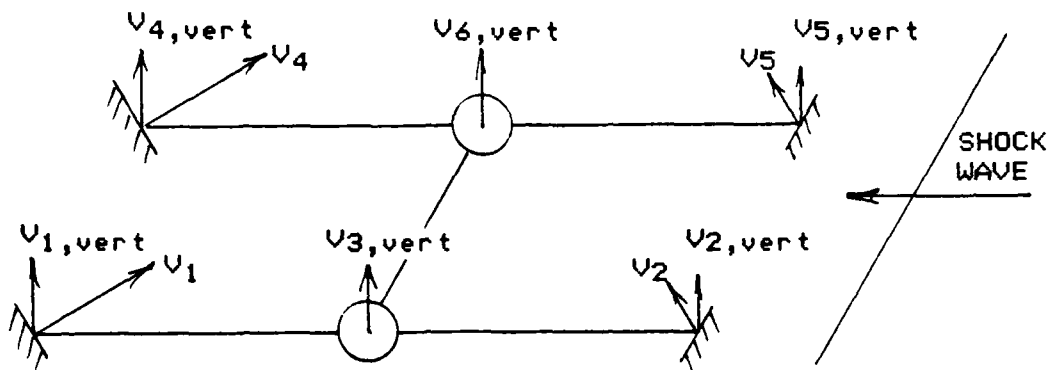
Vertical Relative Velocity of Nodes 3 & 6 wrt fixed base
Nodes (shock wave from ATHWARTSHIP)
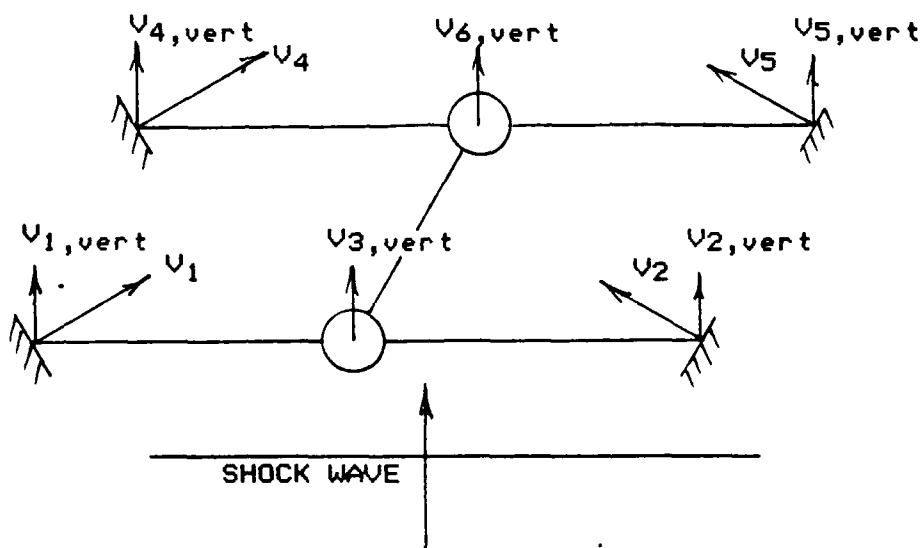
Vertical Relative Velocity of Nodes 3 & 6 wrt fixed base
Nodes (shock wave from below keel)

$$V_{3,rel} = V_{3,vert} - (V_{1,vert} + V_{2,vert})/2$$
$$V_{6,rel} = V_{6,vert} - (V_{4,vert} + V_{5,vert})/2$$

Figure 8 - Case II & III Relative Velocity Calculations for
Athwartship and Vertical Shock Waves

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After the ELSHOK results were obtained for each model,
DDAM was used to calculate the maximum deflections using
the information saved from the SAPIV runs. A file was con-
structed, using an editing program, to input the masses,
natural frequencies, and mode shapes for the model to the
DDAM program. During execution, the program utilizes
prompts to query the user about the type of installation
and shock input direction. The maximum relative deflection
is calculated by the NRL formula [Ref. 12]:

$$\Delta_m = abs(\Delta_{i,max}) + \sqrt{\Sigma(\Delta_i)^2 - \Delta_{i,max}^2} \qquad (5)$$

where;

$abs(\Delta_{i,max})$ = the largest modal deflection of a
point on the model

Δ_i = modal relative deflection at a point on
the model

Δ_m = maximum relative deflection of a point on
the model

This formula is used to reflect the fact that all modes do
not experience their maximum delections simultaneously.

Figures (9), (10), and (11) summarize the model
configurations and shock input directions for cases I, II,
and III. Tables IV, V, and VI are summaries of the in-
formation used in the DDAM and ELSHOK calculations of these
cases. A full case I analysis is presented in Appendix C.

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1414"

5000 lb TNT

2000"

10000 lb TNT

2450"

15000 lb TNT
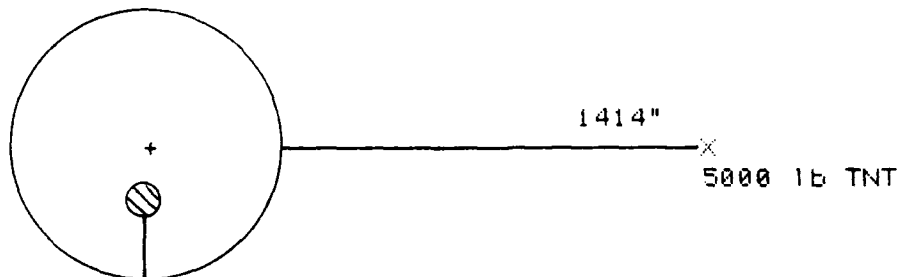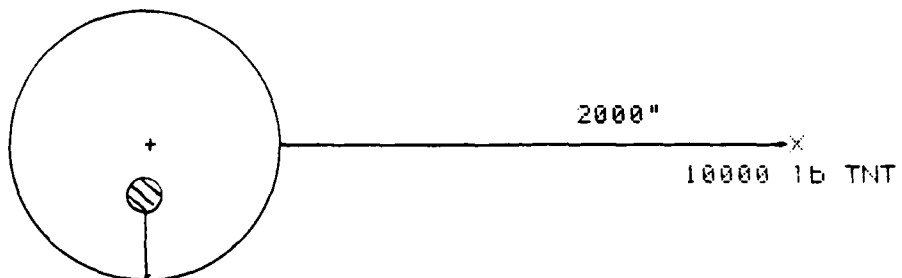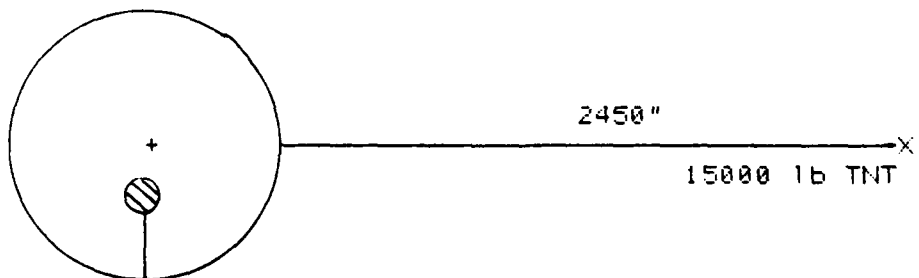
Figure 9 - Shock configurations for Case I

(a)

1414"
X
5000 lb TNT

(b)

2000"
X
10000 lb TNT

(c)

2450"
X
15000 lb TNT

(d)

1414"
X
5000 lb TNT
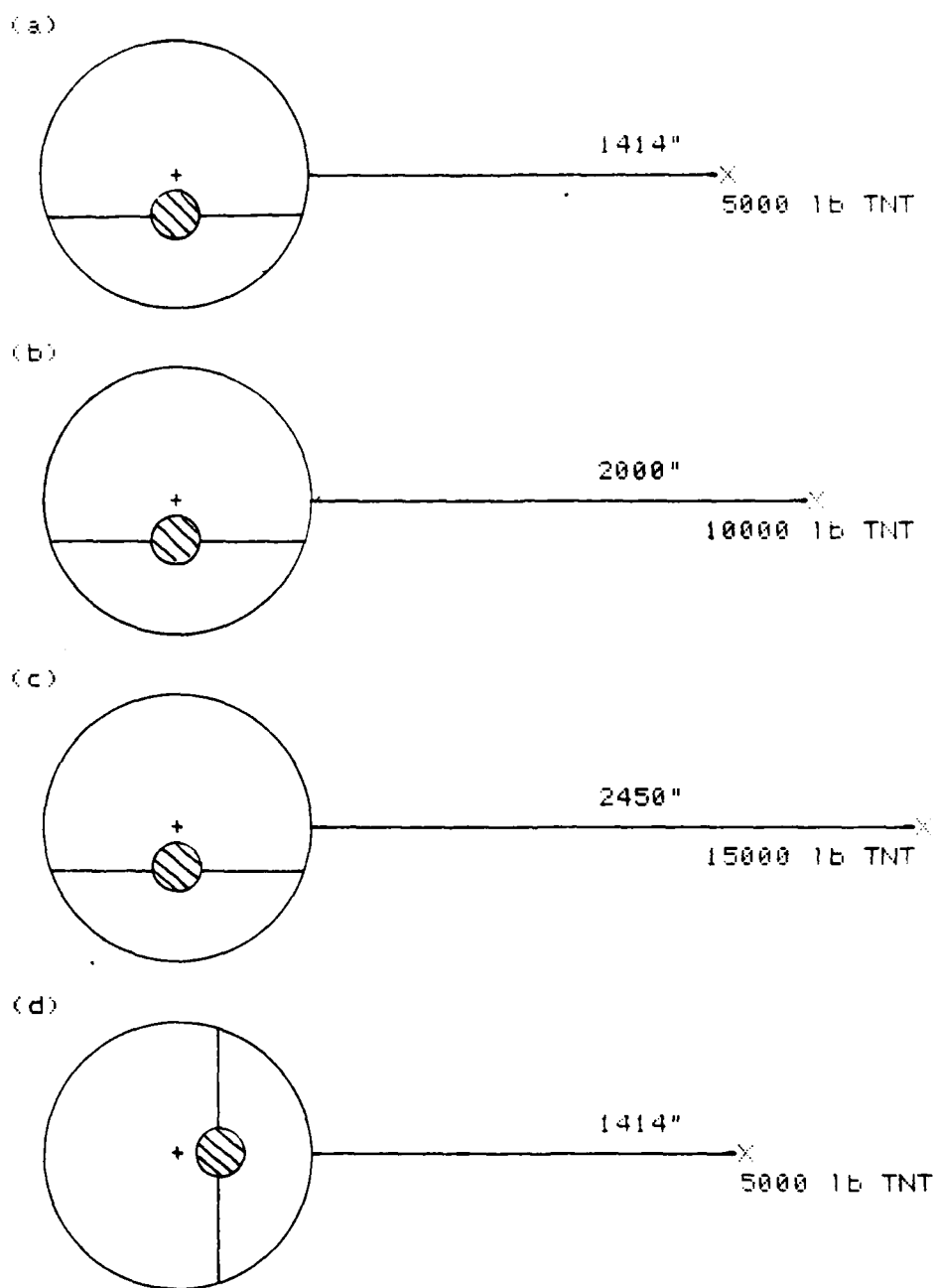
Figure 10 - Shock configurations for Case II

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(a)

1414"

5000 lb TNT

(b)

1414"

5000 lb TNT
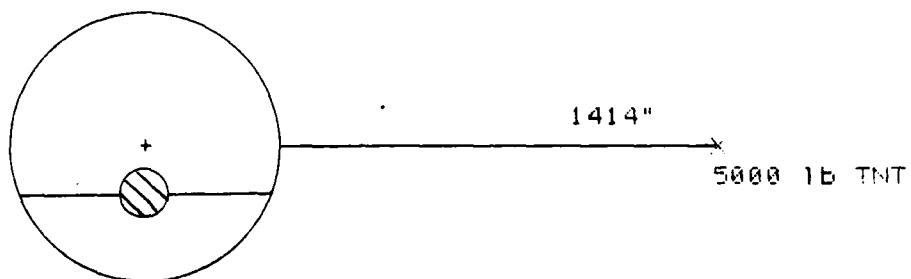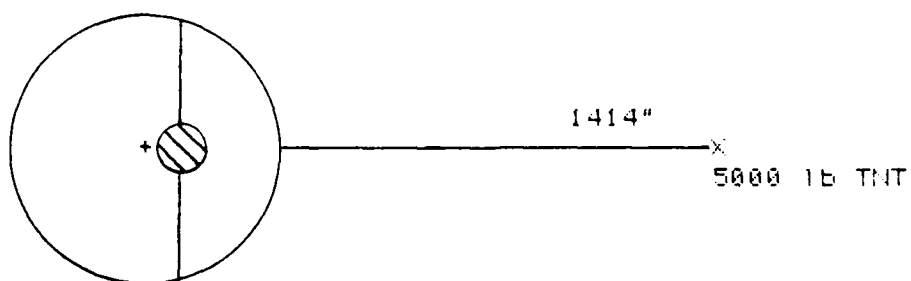
Figure 11 - Shock configurations for Case III

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TABLE IV - Case I Inputs to DDAM and ELSHOK

```
Number of Degrees of Freedom                    18
Number of Connected Degrees of Freedom           3
Number of Unconnected Degrees of Freedom        15

Number of Interface Points                       1

Number of Frequencies In Analysis               10

Substructure Natural Frequencies (cps)

1    445.41       5    7608.71      8   12169.6
2   1054.85       6    9558.05      9   12284.0
3   1343.07       7   10454.9      10   18014.2
4   4037.05

Number of Time Steps In the Analysis          1201
Size of Time Steps                      0.5E-6 sec.
```

TABLE V - Case II Inputs to DDAM and ELSHOK

```
Number of Degrees of Freedom                    34
Number of Connected Degrees of Freedom           4
Number of Unconnected Degrees of Freedom        30

Number of Interface Points                       4

Number of Frequencies In Analysis                5

Substructure Natural Frequencies (cps)

1    48.7743      4    551.148
2   392.390       5    583.723
3   392.508

Number of Time Steps In the Analysis          1201
Size of Time Steps                      1.0E-5 sec.
```

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TABLE VI - Case III Inputs to DDAM and ELSHOK

Number of Degrees of Freedom   34
Number of Connected Degrees of Freedom   4
Number of Unconnected Degrees of Freedom   30

Number of Interface Points   4

Number of Frequencies In Analysis   10

Substructure Natural Frequencies (cps)

1	52.7625	5	570.582	8	1213.51
2	380.0991	6	853.971	9	1483.73
3	381.061	7	1213.45	10	1492.67
4	537.903				

Number of Time Steps In the Analysis   1801
Size of Time Steps   2.0E-5 sec.

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VI. RESULTS

Although the number of cases and their permutations
explored in this investigation are not numerous, they have
been contrived to accentuate the similarities and differ-
ences between the DDAM and ELSHOK methods of analysis. As
mentioned previously, ELSHOK provides a great deal more
information about the shock response of submarine-installed
equipment than DDAM. However, DDAM is not intended to be a
theoretical tool but rather is simply a design check. For
this reason, where ELSHOK will predict different maximum
deflections depending on charge weight and standoff, DDAM
will predict only one value for all variations.

A.   CASE I (1,000 LB CASE)

The predicted responses of DDAM and ELSHOK compare well
for this case. The DDAM calculation yields a maximum de-
flection of 0.0143" for the end of the cantilever beam when
subjected to an athwartship shock input, whereas the ELSHOK
calculation predicted a 0.0131" deflection for a 10,000 lb
charge and a 2,000 inch standoff as in fig (9b). The
15,000 lb and 5,000 lb charges both caused slightly lower
deflections. In this case, DDAM is more conservative
(about 9%) than the ELSHOK calculation. This illustrates
that where the equipment weight is only about 1,000 lb,

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little interaction is to be expected between the hull

response which is relatively low frequency, and the higher

frequency equipment response. The highest hull frequency

is only about 100 Hz. Coupling effects between the

responses of the equipment mass and the hull mass are

insignifigant due to the large ratio of the masses. If the

mass of only segment five in the full model is considered

to be the entire hull mass, then the effective mass of the

hull is about 4100 slugs. The mass of the model is less

than 2.9 slugs. This yields a mass ratio of about 0.00073.

DDAM is based upon the approximation that the hull mass can

be considered infinite which implies a mass ratio of

0.00000... providing no account for coupling other than

through the safety factor built into its design spectrum.

The close agreement between ELSHOK and DDAM is probably due

to the lack of response coupling in both methods of

analysis.

B. CASE II (20,000 LB CASE)

Two equipment configurations were investigated in the

ELSHOK analyses for this case. In the problem geometry in

which the submarine is side loaded, figure (9c), the

maximum deflection is again in good agreement with that

predicted by DDAM; 0.2433 inches in the former versus

0.2744 in the latter. However, the input motion to the

structure is not primarily in the direction of maximum

deflection in this instance. In the second configuration

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of this case, corresponding to figure (9d), a much greater
deflection (133% greater) is predicted by ELSHOK.   There
are two possible explanations. Some hull/structure
interaction is to be expected because the fundamental
natural frequency of the substructure is 48.8 Hz which
falls in the middle of the entire range of hull frequen-
cies. If, as in the former case, a hull effective mass of
4100 slugs is assumed, and the model mass is 67.4 slugs in
this case, then the ratio of the masses is increased to
0.0164 or about 1.6 percent. In this example, the influ-
ence of coupling on the response can be expected to amplify
the expected result for an infinite mass hull system
considerably. Also a source of uncertainty is the test data
upon which the shock input spectrum used in DDAM is based.
Most explosive tests are set up with the charge geometry of
figure (9c) to avoid problems associated with bubble migra-
tion to the hull due to bouyancy effects. In the second
configuration, figure (9d), the charge was situated as if
it had detonated beneath the keel of the submarine, a
realistic possibility when considering modern weapons
tactics but perhaps not simulated well by explosive test-
ing. This particular configuration subjects the structure
to greater shock input motions in its more flexible direc-
tion producing the larger deflections, however DDAM
provides the same inputs for both problems.

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C. CASE III (10,000 LB CASE)

Two equipment configurations were investigated in the
ELSHOK analysis for this case. The results are very
similar to the results for case II. In the configuration
of Fig. 10(a), a maximum deflection of 0.2184 inch was
predicted and in the configuration of Fig 10(b), a maximum
deflection of 0.692 inch was predicted by ELSHOK whereas
DDAM predicted a maximum of 0.2743 inch for both config-
urations. Again, the same possible causes can be cited for
the large (150%) difference in the second instance. In
this case the fundamental frequency of the foundation is
52.7 Hz. The mass of the equipment model in this case is
36.0 slugs yielding a mass ratio between the hull and
substructure of about 0.00877.

A summary of the calculated results is presented in
Table VII. With the limited calculations available in this
work, no attempt could be made to deduce systematically the
exact cause for discrepancies between ELSHOK and DDAM in
cases II and III.

TABLE VII SUMMARY OF RESULTS

CASE NUMBER	EQUIP. WEIGHT	CHARGE WEIGHT	STANDOFF	MAXIMUM DEFLECTIONS (in.)	
				DDAM	ELSHOK
UNITS	(lbs)	(lbs TNT)	(in.)	(in.)	(in.)
Ia	1000	5000	1414	0.0143	0.0119
Ib	1000	10000	2000	0.0143	0.0131
Ic	1000	15000	2450	0.0143	0.0125
IIa	10000	5000	1414	0.2744	0.1888
IIb	10000	10000	2000	0.2744	0.2138
IIc	10000	15000	2450	0.2744	0.2433
IId	10000	5000	1414	0.2744	0.6390
IIIa	20000	5000	1414	0.2763	0.2184
IIIb	20000	5000	1414	0.2763	0.6920

VII CONCLUSIONS

Since its adoption by the naval shock community, DDAM
has provided an easy-to-use and convenient means to design
check equipment installations proposed for submarines. It
is independent of any well defined submarine structural
input and can be applied early in the overall design pro-
cess before such details are well developed. However, the
same qualities that allow for the flexibility in DDAM may
also contribute to possible inaccuracies when this method
is applied to submarines of radically different size or
design than the ones reflected in the empirical Design
Spectrum.

The work in this thesis is in no way construed to be
an all-encompassing evaluation of DDAM and ELSHOK. From
the infinite number of possible equipment configurations
and sizes, three simple models have been selected which ex-
amine only the hull mounted equipment problem. The intent
of this investigation has been to examine the capability of
the two methods to predict the shock response of these
equipments and not to rank one against the other. ELSHOK
or any variation of this code is much too complex and
computer resource intensive to use as a design tool and was
not intended for this purpose.

In the case of equipment whose response is relatively high frequency compared to the hull response, DDAM and ELSHOK deflection predictions are in good agreement. The maximum hull response frequency is limited to about 100 Hz for the 6900 LT submarine used in this work. The good correlation is attributed to the lack of interaction and coupling effects between the hull and substructure. When the response frequencies of the substructure approached those of the hull and the mass of the substructure became a significant portion of the overall system, the comparisons between ELSHOK and DDAM deflection predictions were not good.

The indications of this work are that DDAM does not correctly reflect the hull-substructure response coupling amplification which becomes apparent when the substructure response is tuned to the hull response. Additionally, the empirical database upon which DDAM is reliant for shock input may fail to represent the heavy equipment problem well.

More basic research remains to be done before many of the questions or criticisms posed by this thesis can be considered conclusive. Due to the scarcity of published reports describing the input data used to generate the design shock values used by DDAM, the application of this method as a general design qualification should be regarded

with caution. The basis of the Design Spectrum used in DDAM should be available for analysis and revision.

Additional work remains to be done to determine where the discrepancies between ELSKOK and DDAM first become significant. The cases analyzed here represent both ends of the substructure response spectrum but lend little information to what happens in the transition region between the low-interaction and high-interaction frequency response regimes.

DDAM should be retained as a design check method. However, some modifications are recommended here. The present Design Shock inputs used in DDAM should be updated to reflect the incresed size of modern day submarines. If the details of the original formulation were Known or revealed, the current values could be updated by generating new analytical data based on computer simulations. This new spectrum could then be verified by explosive testing. It is apparent from the hull-substructure coupling phenomenon noted here that a modified shock spectrum should be formulated for each new class of submarine which would reflect the peculiarities of this class versus the previous ones.

At the present time, when new submarines cost billions of dollars and are by no means numerous, every effort must be made to ensure their survival in an underwater explosive

shock environment. This should include taking a new look

at DDAM and ensuring it upholds the standards set by naval

shock policy. There is a great deal of flexibility inher-

ent in DDAM and together with modern numerical techniques

it can be updated to reflect current technology.

LIST OF REFERENCES

1. Department of the Navy Military Specification
    MIL-S-901C (NAVY), Shock Tests, H.I. (High-Impact)
    Shipboard Machinery, Equipment, and Systems,
    Requirements For, 15 January 1963

2. Naval Research Laboratory Memorandum Report 1396,
    Interim Design Values For Shock Design of Shipboard
    Equipment, by R. O. Belsheim and G. J. O'Hara, February
    1963

3. Geers, T. L., "Residual Potential and Approximate
    Methods For Three-Dimensional Fluid-Structure
    Interaction Problems", Journal of the Acoustical
    Society of America, v. 49, No. 5, (Part 2),
    pp. 1505-1510, 1971

4. R. Vasudevan and D. Ranlet, Submerged Shock Response
    of a Linearly Elastic Shell of Revolution Containing
    Internal Structure : User's Manual For the ELSHOCK
    Code, Weidlinger Associates, New York, New York, May
    1982

5. Naval Research Laboratory Report 5545, Shock Design of
    Shipboard Equipment, by R. O. Belsheim and
    G. J. O'Hara, September 1960

6. Butt, L., Naval Ship Shock Design Analysis, lecture
    notes presented at Naval Postgraduate School, ME 4902,
    Winter 1984

7. D. Ranlet, F. L. DiMaggio, H. H. Bleich and M. L Baron,
    "Elastic Response of Submerged Shells With Internally
    Attached Structures to Shock Loading", International
    Journal of Computers and Structures, v. 7, No. 3,
    pp. 355-364, June 1977

8. D. Ranlet and F. L. DiMaggio, "Transient Response of
    Shells With Internally Attached Structures",
    International Journal of Computers and Structures,
    v. 9, No. 5, pp.475-481, November 1978

9.   D. Bushnell, <u>Stress, Stability and Vibration of
     Complex Branched Shells of Revolution : Analysis and
     User's Manual for BOSOR4</u>, LMSC-D24 3605, Lockheed
     Missles and Space Company, Inc., Sunnyvale,California,
     March 1972

10. Earthquake Engineering Research Center Report No.
     EERC 73-11, <u>SAPIV-A Structural Analysis Program for
     Static and Dynamic Response of Linear Systems</u>, by
     K. J. Bathe, E. L. Wilson and F. E. Peterson,
     University of California, Berkley, California, April
     1974

11. American Institute of Steel Construction, Inc., <u>Manual
     of Steel Construction</u>, 7th ed., pp. 50-51, 1970

12. Naval Sea Systems Command, NAVSEA 0908-LP-000-3010,
     <u>Shock Design Criteria for Surface Ships</u>, p. 21, May
     1976

13. Heilborn, J., <u>Science and Engineering Programs
     Apple II Edition</u>, pp. 97 - 104, Osborne/McGraw Hill,
     1981

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APPENDIX A : DDAM USER'S MANUAL AND PROGRAM LISTING

The DDAM Program contained herein provides an easy means to perform a small to medium-scale DDAM analysis of a given internal equipment design. The program is written in IBM PC BASIC language and is not restricted to submarine analyses only but includes the standard DDAM case possibilities. The solution algorithm follows the method cited in Ref. 2.

A. USING THE DDAM PROGRAM

A.1. Option Selections

The DDAM program is menu-driven and written to be self-explanatory. Prior to starting the program, it must be available on a diskette along with the BASICA.COM program.

To start the program type:

```
BASICA<ENTER>
<F3>DDAM<ENTER>
<F2>
```

The first command line loads and executes the BASIC inter-preter and the second line loads the DDAM program. The third line starts execution of the DDAM Program.

Upon starting, the title of the program (DDAM) is written on the screen and several seconds later a message

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appears describing the provided functions. Follow the
directions.

Four execution options will appear for source of
data and program exit to the operating system. They are:

[1] Input Mode Shapes and Mass Matrix for the
     problem from Keyboard

[2] Input Mode Shapes and Mass Matrix from a
     disk file

[3] Input a Mass Matrix and Stiffness Matrix
     for previously formulated equations of motion

[5] Exit to DOS

No option [4] is present; however, provisions have been
made to install a user-defined subroutine at line 25000 in
the program.

Option [1] is useful for small problems and is not
recommended for situations involving more than four degrees
of freedom. It allows all data input to be carried out
using the keyboard. In larger problems, the entry of mode
shapes becomes tedious and error prone.

Option [2] is recommended for most problems. It
allows the use of a diskfile for input. The file is
user-specified and utilizes a free-format data structure.
The information must be present in the file in a set order
which is described later.

Selection of option [3] causes a message to be displayed stating that the JACOBI program must first be run to solve the eigenvalue problem for mode shapes and natural frequencies. This program listing follows the DDAM listing in this appendix. Incorporating the JACOBI program in DDAM would have reduced significantly the size of problem which could be handled. The JACOBI program is included as a convenience to the reader and was not integral to the analysis of the case studies done in this thesis. Its operation is described later.

A.2. Option[1] Execution

Selecting option [1] allows input of the masses, modes, and natural frequencies of the problem from the keyboard. The number of modes and masses are first input. A mass input subroutine queries the user interactively for the diagonal entries of the mass matrix. After input is completed, the diagonal elements are displayed enabling the user to make corrections as necessary. A zero correction terminates mass matrix input. Next, the program asks for input of the natural frequencies of the system. It requires one natural frequency for each mode shape. The input format is similar to the one used to input the mass elements. The natural frequencies are required in units of radians/second. Each mode shape is then input. After initializing each mode, a correction option is provided.

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The program next calculates the participation factors and modal weights for the problem.

Following these preliminary steps, DDAM requires information to fix the installation details for the equipment and type of analysis to be carried out. The standard cases of Ref. 2 are allowed. Once the case is fixed, the Design Values are calculated and displayed as DA(1)...DA(n) where n is the number of modes selected for the analysis. The Design Values are the equivalent static accelerations calculated from empirical formulas for each mode.

Several output options are provided. Modal forces or deflections or both can be selected. After selection, the appropriate calculations are made and the results displayed. Initially a print option was separately provided. However, in the present version, selection of the display to screen option with printer on will cause output to go to the screen and the printing device. Disabling the printer will cause output to go only to the screen. Following the output options, choices are provided to change the equipment installation type and repeat the analysis or to exit the program.

A.3. <u>Option [2] Execution</u>

Selecting option [2] allows input of masses, natural frequencies, and mode shapes from a disk file. After the data is read in, the program execution is similar to that in option [1]. Option [2] prompts the user for the

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dimension of the mass matrix, the number of modes in the
analysis, and the name of the input file. The input file
is a free-format ASCII file containing the masses, natural
frequencies, and mode shapes for the problem. This file
may be constructed from structural analyzer (SAPIV) output
or any other problem formulation method using a suitable
editor program. (EDLIN, the editor provided with the "IBM
Disk Operating System" is not recommended for this purpose
due to its line orientation.) The format for the input
file follows:

```
          mass(1)  .... mass(m)        (slugs)
          omega(1) .... omega(m)       (rad/s)
          phi(1,1) .... phi(1,n)
          phi(m,1) .... phi(m,n)

          where     m = number of masses and
                    n = number of modes in the analysis
```

In the above format, the data is read in sequentially from
left to right. The data is echoed to the screen and/or
printer in order to provide a check for proper input
operation.

B. PROGRAM LISTING - D D A M


```
10 CLS: KEY OFF : LOCATE 8,1,0
20 PRINT"**********************************************************************
****"
21 PRINT"**
  **"
30 PRINT"**      DDDD      DDDD      AAA       MMM   MMM
  **"
40 PRINT"**      DD  D     DD  D     A  A      MM M MM
  **"
50 PRINT"**      DD  D     DD  D     AAAAAAA   MM M MM
  **"
60 PRINT"**      DD  D     DD  D     A    A    MM     MM
  **"
70 PRINT"**      DDDD      DDDD      A    A    MM     MM
  **"
80 PRINT"**
  **"
90 PRINT"**      DYNAMIC   DESIGN    ANALYSIS      METHOD
  **"
100 PRINT"**
  **"
110 PRINT"**
  **"
120 PRINT"**********************************************************************
****"
121  DIM MASS(40)
122  DIM PHI(40,40)
123  DIM W(40)
124 DIM MX(40,40),MX2(40,40),SUM1(40),SUM2(40),P(40)
125 DIM WA(40)
127 DIM V0(40),A0(40),DA(40)
128 DIM AA(40),VA(40),F(40,40),DEFL(40),DELTA(40,40)
130 FOR I = 1 TO 5000 : NEXT I
140 CLS: LOCATE 1,1,0
150 PRINT"   The purpose of this program is to allow the user a convenient meth
od":PRINT
160 PRINT"by which to carry out a small to medium sized DDAM analysis of a give
n":PRINT
170 PRINT"piece of equipment.  Familiarity with NORMAL MODE ANALYSIS and some u
n-":PRINT
180 PRINT"derstanding of the theory behind DDAM is prerequisite to confident us
e":PRINT
190 PRINT"of this program. The program is prompt driven but the user should hav
e ":PRINT
200 PRINT"available to him / her either :":PRINT:PRINT
210 PRINT"            A.)   Mode Shapes and a Mass Matrix for the"
220 PRINT"                  problem of interest.":PRINT:PRINT
230 PRINT"            B.)   A Mass Matrix and Stiffness Matrix from"
```

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```
240 PRINT"                    previously formulated EQUATIONS of MOTION":PRINT
:PRINT:PRINT
250 PRINT"              ( Press ANY key to continue )":LOCATE 25,1,0
260 A$ = INKEY$: IF A$ = "" THEN 260
270 CLS:
280 LOCATE 5,1,0
290 PRINT"  In order to initialize the program input, choose one of the follow
ing":PRINT
300 PRINT"menu selections =====)":PRINT:PRINT
310 LOCATE 10,20,0 :PRINT"[1] Input Mode Shapes and Mass Matrix"
320 LOCATE 11,20,0 :PRINT"    for the problem from keyboard"
325 LOCATE 13,20,0 :PRINT"[2] Input Mode Shapes and Mass Matrix"
326 LOCATE 14,20,0 :PRINT"    from a disk file "
330 LOCATE 16,20,0 :PRINT"[3] Input a Mass Matrix and Stiffness Matrix"
340 LOCATE 17,20,0 :PRINT"    for previously formulated equations of"
350 LOCATE 18,20,0 :PRINT"    motion"
360 LOCATE 20,20,0 :PRINT"[5] Exit to DOS"
370 A$ = INKEY$ : IF A$ )= CHR$(49) AND A$ <= CHR$(53) GOTO 400
380 IF A$ = "" GOTO 370
390 BEEP : GOTO 370
400 B = VAL(A$) : CLS
410 ON B GOSUB 5000,15000,20000,25000,500
500 SYSTEM :END
600 '***********************************************************************
601 '     S U B R O U T I N E   T O   I N P U T   M A S S   M A T R I X
603 '***********************************************************************
605 INPUT "Enter the dimension of the Mass Matrix ==)  "; N
610 IF N <= 20 GOTO 622
620 PRINT:PRINT:PRINT"*****  PROBLEM SIZE IS LIMITED TO 20 X 20 MATRICES  ****
* ":PRINT:PRINT: GOTO 600
621 PRINT:PRINT:PRINT   .
622 INPUT "Enter the number of modes you wish to use ==) ";M
630 CLS: PRINT"***** Enter the elements of the DIAGONAL Mass Matrix *****":PRI
NT:PRINT
640 PRINT"      If you make an error you will have an opportun-"
650 PRINT"                ity later to correct it.":PRINT:PRINT
670 FOR I = 1 TO N
680 PRINT "   M(";I;",";I;") = ";:INPUT" ", MASS(I)
690 IF (I = 5) OR (I = 10) OR (I = 15) THEN CLS
700 IF MASS(I) () 0 GOTO 730
710 PRINT" ***** MASS MATRIX MUST BE POSITIVE DEFINITE --- INPUT NON-ZERO VALU
E ****"
720 PRINT: GOTO 680
730 PRINT: NEXT I
740 CLS
750 FOR I = 1 TO N
760    PRINT "M(";I;",";I;") = ";MASS(I),
770 NEXT I
780 PRINT:PRINT:PRINT
790 PRINT"Enter diagonal element number to correct mistaken entries or "
800 PRINT:INPUT "          Enter ( ZERO ) to continue ==)", RESPONSE
```

```basic
810 IF RESPONSE = 0 THEN RETURN
820 IF RESPONSE <= 0 OR RESPONSE > N  THEN CLS : GOTO 750 ELSE I = RESPONSE
850 PRINT:PRINT:INPUT "Enter correct element value ==> ", M(I)
860 PRINT:PRINT"M(";I;",";I;") CHANGED TO ";MASS(I)
870 FOR I = 1 TO 1500 : NEXT I : CLS : GOTO 750
880 RETURN
1000 '***********************************************************************
1010 '        S U B R O U T I N E  T O  I N P U T  M O D E  S H A P E S
1020 '***********************************************************************
1050 CLS: LOCATE 5,1,0
1060 PRINT"***** Enter OMEGA's corresponding to Mode Shapes *****":PRINT
1070 PRINT"                  ( smallest to largest )":PRINT:PRINT
1080 FOR I = 1 TO M
1090 PRINT "    omega(";I;") == ";:INPUT" ",W(I)
1100 IF (I=5) OR (I=10) OR (I=15) THEN CLS
1110 NEXT I
1120 CLS : FOR I = 1 TO M
1130    PRINT"OMEGA(";I;") = ";W(I),
1140 NEXT I
1150 PRINT:PRINT:PRINT
1160 PRINT "Enter frequency number to correct mistaken entries or ":PRINT
1170 INPUT "                    Enter < ZERO > to continue ==>",RESPONSE
1180 IF RESPONSE = 0 THEN GOTO 1230
1190 IF RESPONSE <= 0 OR RESPONSE > N  THEN CLS : GOTO 1120 ELSE I = RESPONSE
1200 PRINT:PRINT:INPUT "Enter correct frequency value ==> ", W(I)
1210 PRINT:PRINT"OMEGA(";I;")  changed to ";W(I)
1220 FOR I = 1 TO 2000 : NEXT I : GOTO 1120
1230 CLS: LOCATE 5,1,0
1240 PRINT"***** Enter EIGENVECTOR's corresponding to Mode Shapes *****":PRINT
1250 PRINT"                ( begin with Mode One )":PRINT:PRINT
1260 FOR I = 1 TO M
1270    FOR J = 1 TO N
1280          PRINT"   MODE SHAPE ";I;"  Phi(";J;") == ";:INPUT" ",PHI(I,J)
1290          IF (J=5) OR (J=10) OR (J=15) THEN CLS : LOCATE 5,1,0
1300    NEXT J
1305    CLS : PRINT:PRINT
1310    PRINT "*************** M O D E   N U M B E R   ";I;" ***************"
1320    PRINT:PRINT:FOR J = 1 TO N
1330          PRINT" Phi(";J;") = ";PHI(I,J),
1340    NEXT J
1350    PRINT:PRINT
1360    PRINT"Enter element number in mode to change or":PRINT
1370    INPUT"      Enter < ZERO > to continue ==> ", RESPONSE
1380    IF RESPONSE = 0 THEN GOTO 1430
1390    IF RESPONSE <= 0 OR RESPONSE > N THEN CLS:GOTO 1310 ELSE J = RESPONSE
1400    PRINT: INPUT"Enter correct element value ==>";PHI(I,J):PRINT
1410    PRINT"Phi(";J;")  CHANGED TO ";PHI(I,J)
1420    FOR K = 1 TO 2000 : NEXT K : CLS : GOTO 1310
1430 CLS:NEXT I
1440 RETURN
5000 '***********************************************************************
```

```basic
5005 '   S U B R O U T I N E  TO  D R I V E  M O D E / M A S S  I N P U T
5010 '*****************************************************************************
5020 LOCATE 5,1,0
5030 PRINT" The program has been initialized to allow user input of the":PRINT
5040 PRINT"Mode Shapes and Mass Matrix.  If you desire one of the other op-":PR
INT
5050 PRINT"tions, PRESS < escape key >; ......otherwise =>":PRINT:PRINT
5055 PRINT"       PRESS < space bar > to continue )"
5060 A$ = INKEY$ : IF A$ = CHR$(27) GOTO 270
5070 IF A$ <> CHR$(32) GOTO 5060
5075 CLS : LOCATE 5,1,0 : GOSUB 600
5080 CLS : LOCATE 5,1,0 : GOSUB 1000
5090 CLS : GOSUB 6000
5100 CLS: LOCATE 25,1,0
5110 PRINT
5120 GOSUB 8000
5130 CLS: GOSUB 8200
5140 CLS : GOSUB 10000
6000 '*****************************************************************************
6010 '    S U B R O U T I N E  TO  F I N D  P A R T I C I P A T I O N
6020 '                    F A C T O R S
6030 '*****************************************************************************
6040 LOCATE 25,1,0
6050 T$(1) = TIME$
6060 PRINT"   CALCULATING PARTICIPATION FACTORS == start : ";TIME$
6080 FOR I = 1 TO M
6090    FOR J = 1 TO N
7000         MX(I,J) = MASS(J) * PHI(I,J)
7010         MX2(I,J) = MX(I,J) * PHI(I,J)
7020    NEXT J
7030 NEXT I
7040 FOR I = 1 TO M
7050    SUM1(I) = MX(I,1)
7060    SUM2(I) = MX2(I,1)
7070    FOR J = 2 TO N
7080         SUM1(I) = SUM1(I) + MX(I,J)
7090         SUM2(I) = SUM2(I) + MX2(I,J)
7100    NEXT J
7110 NEXT I
7120 FOR I = 1 TO M
7130    P(I) = SUM1(I) / SUM2(I)
7140 NEXT I
7150 FOR I = 1 TO M
7160    MBAR(I) = P(I) * SUM1(I)
7170 NEXT I
7180 LOCATE 25,60,0 : PRINT"  done:  ";TIME$
7190 DUMMY = M
7200 IF DUMMY > 10 THEN K% = M/2 ELSE K% = M
7210 L=1:J=0
7215 LOCATE 5,1,0
7220 PRINT"***** PARTICIPATION FACTORS AND MODAL MASSES *****":PRINT:PRINT
```

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```
7221 LPRINT"***** P  F A C T O R S  A N D  M O D A L  M A S S E S *****"
7222 LPRINT
7225 PRINT" N    MODAL PARTICIPATION          MODAL MASS "
7226 PP$ ="##       ##.######^^^^          ##.######^^^^"
7227 LPRINT" N    MODAL PARTICIPATION          MODAL MASS "
7230 FOR I = L TO K%
7240    PRINT USING PP$ ; I,P(I),MBAR(I)
7241    LPRINT USING PP$ ; I,P(I),MBAR(I)
7250    J = J + 1
7260 NEXT I
7270 IF DUMMY > 10 AND J < 11 THEN A$ = INKEY$:GOTO 7280 ELSE GOTO 7311
7280    PRINT:PRINT:PRINT
7281 LPRINT:LPRINT
7290    PRINT"                         PRESS ANY KEY TO CONTINUE..."
7300    IF A$ = "" THEN GOTO 7300
7310    K% = M : L = 10: CLS : GOTO 7215
7311 PRINT:PRINT:PRINT"                         PRESS ANY KEY TO CONTINUE..."
7320 A$ = INKEY$ : IF A$ = "" THEN GOTO 7320
7330 RETURN
8000 '**************************************************************
8010 '        S U B R O U T I N E  T O  C A L C U L A T E  M O D A L
8020 '                        W E I G H T S
8030 '**************************************************************
8035 CLS:LOCATE 5,1,0
8040 PRINT"***** C A L C U L A T E D  M O D A L  W E I G H T S *****"
8041 LPRINT"***** C A L C U L A T E D  M O D A L  W E I G H T S *****"
8045 WW$ = "##       ###.######"
8046 PRINT : PRINT " N    WEIGHT IN KIPS"
8047 LPRINT " N    WEIGHT IN KIPS"
8050 PRINT
8051 LPRINT
8070 FOR I = 1 TO M
8080    WA(I) =386 * SUM1(I) * P(I) / 1000
8090    PRINT USING WW$ ; I,WA(I)
8091    LPRINT USING WW$ ; I,WA(I)
8095 NEXT I
8100 LPRINT:LPRINT:PRINT:PRINT:PRINT"                         Press any ke
y to continue..."
8110 A$ = INKEY$: IF A$ = "" THEN GOTO 8110
8120 RETURN
8200 '**************************************************************
8210 '      S U B R O U T I N E  T O  D E T E R M I N E  G E O M E T R Y
8220 '          O F  A N A L Y S I S  A N D  A (0)  ,V (0)  ,D (A)
8230 '**************************************************************
8240 PRINT"    Some information is now needed to complete the details about th
e"
8250 PRINT"type of vessel the structure I am analyzing is installed in and whet
her"
8260 PRINT"or  not the analysis is to consider elastic or elastic-plastic defor
ma-"
8270 PRINT"tions."
```

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```
8280 PRINT:PRINT
8290 PRINT"PLEASE ENTER ONE OF THE FOLLOWING =>"
8300 LOCATE 9,20,0: PRINT"[1]   SUBMARINE      ( hull mounted system )"
8310 LOCATE 11,20,0:PRINT"[2]   SUBMARINE      ( deck mounted system )"
8320 LOCATE 13,20,0:PRINT"[3]   SUBMARINE      ( shell plating mounted system )"
8330 LOCATE 15,20,0:PRINT"[4]   SURFACE SHIP   ( hull mounted system )"
8340 LOCATE 17,20,0:PRINT"[5]   SURFACE SHIP   ( deck mounted system )"
8350 LOCATE 19,20,0:PRINT"[6]   SURFACE SHIP   ( shell plating mounted system )"
8360 A$ = INKEY$: IF A$=CHR$(49) AND A$ <= CHR$(54) GOTO 8390
8370 IF A$ = "" THEN GOTO 8360
8380 BEEP: GOTO 8360
8390 B = VAL(A$):CLS
8400 PRINT"ENTER ====>      [1]  for ELASTIC ANALYSIS":PRINT:PRINT
8410 PRINT"                 [2]  for ELASTIC - PLASTIC ANALYSIS "
8420 A$ = INKEY$ : IF A$ >= CHR$(49) AND A$ <= CHR$(50) GOTO 8450
8430 IF A$ = "" THEN GOTO 8420
8440 BEEP: GOTO 8420
8450 C = VAL(A$)
8460 IF C=2 AND (B = 3 OR B = 6) THEN GOTO 8470 ELSE GOTO 8500
8470 PRINT:PRINT:PRINT:PRINT"***** ELASTIC - PLASTIC OPTION NOT AVAILABLE FOR **
***":PRINT
8480 PRINT"*****        SHELL PLATING MOUNTED SYSTEMS          *****"
8481 LOCATE 10,20,0
8482 PRINT" PRESS ANY KEY TO CONTINUE ....
8483 A$ = INKEY$ : IF A$ = "" THEN GOTO 8483
8490 CLS:GOTO 8240
8500 CLS:LOCATE 5,1,0
8510 PRINT"ENTER ====>      [1]  for motion in VERTICAL      direction":PRINT
8520 PRINT"                 [2]  for motion in ATHWARTSHIP  direction":PRINT
8530 PRINT"                 [3]  for motion in FORE AND AFT direction"
8540 A$ = INKEY$: IF A$ >= CHR$(49) AND A$ <= CHR$(51) GOTO 8570
8550 IF A$ = "" THEN GOTO 8540
8560 BEEP: GOTO 8540
8570 D = VAL(A$)
8571 IF B = 1 THEN LPRINT" SUBMARINE      ( hull mounted system )";
8572 IF B = 2 THEN LPRINT" SUBMARINE      ( deck mounted system )";
8573 IF B = 3 THEN LPRINT" SUBMARINE      ( shell plating mounted system )";
8574 IF B = 4 THEN LPRINT" SURFACE SHIP   ( hull mounted system )";
8575 IF B = 5 THEN LPRINT" SURFACE SHIP   ( deck mounted system )";
8576 IF B = 6 THEN LPRINT" SURFACE SHIP   ( shell plating mounted system )";
8577 IF C = 1 THEN LPRINT" for ELASTIC ANALYSIS"
8578 IF C = 2 THEN LPRINT" for ELASTIC - PLASTIC ANALYSIS"
8579 IF D = 1 THEN LPRINT:LPRINT " for motion in VERTICAL      direction":LPRINT
8580 IF D = 2 THEN LPRINT:LPRINT " for motion in ATHWARTSHIP  direction":LPRINT
8581 IF D = 3 THEN LPRINT:LPRINT " for motion in FORE AND AFT direction":LPRINT
8590 FOR I = 1 TO N
8600    IF B <> 1 THEN GOTO 8680
8610          A0(I) = 10.4* ((480+WA(I))/(20+WA(I)))
8620          V0(I) = 20! * ((480+WA(I))/(100+WA(I)))
8630          IF (D=1 OR D=2) AND C=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8640          IF (D=3 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
```

```basic
8650        IF (D=1 OR D=2) AND C=2 THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8660        MULT1=.4 : MULT2=.2
8670    GOTO 9110
8680    IF B <> 2 THEN GOTO 8780
8690        A0(I) = 5.2 * ((480 + WA(I))/(20 + WA(I)))
8700        V0(I) = 10! * ((480+WA(I))/(100+WA(I)))
8710        IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8720        IF (D=2 AND C=1) THEN MULT1=2:MULT2=2 : GOTO 9110 ELSE
8730        IF (D=3 AND C=1) THEN MULT1=.8:MULT2=.8 : GOTO 9110 ELSE
8740        IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8750        IF (D=2 AND C=2) THEN MULT1=2:MULT2=1! : GOTO 9110 ELSE
8760        MULT1 = .8 : MULT2 = .4
8770    GOTO 9110
8780    IF B <> 3 THEN GOTO 8850
8790        A0(I) = 52 * ((480+WA(I))/(20+WA(I)))
8800        V0(I) = 100 * ((480+WA(I))/(100+WA(I)))
8810        IF D=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8820        IF D=2 THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
8830        MULT1 = .08 : MULT2 = .08
8840    GOTO 9110
8850    IF B <> 4 THEN GOTO 8950
8860        A0(I) = 20 * ((37.5 + WA(I))*(12 + WA(I))/(6 + WA(I)^2))
8870        V0(I) = 60 * ((12 + WA(I))/(6 + WA(I)))
8880        IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8890        IF (D=2 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
8900        IF (D=3 AND C=1) THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
8910        IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
8920        IF (D=2 AND C=2) THEN MULT1=.4:MULT2=.2 : GOTO 9110 ELSE
8930        MULT1 = .2 : MULT2 = .1
8940    GOTO 9110
8950    IF B <> 5 THEN GOTO 9050
8960        A0(I) = 10 * ((37.5 + WA(I))*(12 + WA(I))/(6 + WA(I)^2))
8970        V0(I) = 30 * ((12 + WA(I))/(6 + WA(I)))
8980        IF (D=1 AND C=1) THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
8990        IF (D=2 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
9000        IF (D=3 AND C=1) THEN MULT1=.4:MULT2=.4 : GOTO 9110 ELSE
9010        IF (D=1 AND C=2) THEN MULT1=1:MULT2=.5 : GOTO 9110 ELSE
9020        IF (D=2 AND C=2) THEN MULT1=.4:MULT2=.2 : GOTO 9110 ELSE
9030        MULT1 = .4 : MULT2 = .2
9040    GOTO 9110
9050        A0(I) = 40 * ((37.5 + WA(I))*(12+ WA(I))/(6 + WA(I))^2)
9060        V0(I) = 120 * ((12 + WA(I))/(6 + WA(I)))
9080        IF D=1 THEN MULT1=1:MULT2=1 : GOTO 9110 ELSE
9090        IF D=2 THEN MULT1=.2:MULT2=.2 : GOTO 9110 ELSE
9100        MULT1 = .1 : MULT2 = .1
9110 V0(I) = MULT2 * V0(I) : A0(I) = MULT1 * A0(I) : NEXT I
9120 FOR I = 1 TO M
9130    AA(I) = A0(I) * 386
9140    VA(I) = V0(I) * W(I)
9150    IF ABS(AA(I)) > ABS(VA(I)) THEN DA(I) = VA(I) ELSE DA(I) = AA(I)
9160    IF ABS(DA(I)) < 2316 THEN DA(I) = 2316
```

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```
9170 NEXT I
9171 CLS: LOCATE 5,1,0
9172 FOR I = 1 TO M: PRINT "DA(";I;") = ";DA(I),
9173 NEXT I
9174 PRINT:PRINT:PRINT"                    Press any key to continue ..."
9175 A$ = INKEY$:IF A$ = "" THEN GOTO 9175 ELSE CLS : LOCATE 5,1,0
9176 FOR I = 1 TO M : LPRINT : LPRINT "DA(";I;") = ";DA(I): NEXT I : LPRINT
9180  RETURN
10000 '***********************************************************************
10010 '      S U B R O U T I N E   T O   C A L C U L A T E   M O D A L
10020 '           F O R C E S   O R   D E F L E C T I O N S
10030 '***********************************************************************
10040 LOCATE 5,1,0
10050 PRINT"   Almost done.... Please ENTER the number of the type of informat
ion"
10060 PRINT:PRINT"you desire as output ===)"
10070 LOCATE 10,1,0 :PRINT"                     [1] MODAL FORCES"
10080 LOCATE 12,1,0 :PRINT"                     [2] MODAL DEFLECTIONS"
10090 LOCATE 14,1,0 :PRINT"                     [3] FORCES & DEFLECTIONS"
10095 LOCATE 16,1,0 :PRINT"                     [4] CHANGE ANALYSIS TYPE"
10096 LOCATE 18,1,0 :PRINT"                     [5] EXIT TO DOS"
10100 A$ = INKEY$: IF A$ >= CHR$(49) AND A$ <= CHR$(53) THEN GOTO 10140
10110 IF A$ = "" THEN GOTO 10100
10130 BEEP : GOTO 10100
10140 FLAG1 = VAL(A$) : CLS
10150 IF FLAG1 = 2 THEN GOTO 10220
10155 IF FLAG1 = 4 THEN GOTO 16160
10156 IF FLAG1 = 5 THEN SYSTEM
10160 REM ****** CALCULATE MODAL FORCES ********
10170 FOR I = 1 TO M
10180    FOR J = 1 TO N
10190         F(I,J) = P(I) * MASS(J) * PHI(I,J) * DA(I)
10200    NEXT J
10210 NEXT I
10220 IF FLAG1 = 1 THEN GOTO 12000
10230 REM ****** CALCULATE MODAL DEFLECTIONS *********
10240   FOR I = 1 TO M
10250    FOR J = 1 TO N
10260         DELTA(I,J) = PHI(I,J) * P(I) * DA(I) / W(I)^2
10290    NEXT J
10300 NEXT I
10310 FOR J = 1 TO N
10320   BIGGEST = 0
10330    FOR I = 1 TO M
10340         IF BIGGEST < ABS(DELTA(I,J)) THEN BIGGEST = ABS(DELTA(I,J)): K=I
10350    NEXT I
10360   S = 0
10370    FOR I = 1 TO M
10380         IF I = K THEN GOTO 10400
10390              S = S + DELTA(I,J)^2
10400    NEXT I
```

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```
18410    DEFL(J) = ABS(DELTA(K,J)) + SQR(S)
18420 NEXT J
12000 REM ********* OUTPUT RESULTS ***********
12010 CLS : LOCATE 5,1,0
12020 PRINT '          ENTER                [1]  TO ECHO RESULTS TO SCREEN":P
RINT:PRINT
12030 PRINT '                               [2]  TO ECHO RESULTS TO PRINTER":
PRINT:PRINT
12040 A$ = INKEY$
12050 IF A$ >= CHR$(49) AND A$ <= CHR$(50) THEN GOTO 12070
12060 IF A$ = "" THEN GOTO 12040 ELSE BEEP: GOTO 12040
12070 FLAG2 = VAL(A$)
12080 IF FLAG2 = 2 THEN GOTO 12300
12090 IF FLAG1 = 2 THEN GOTO 12190
12100 FOR I = 1 TO M
12110    CLS : LOCATE 5,1,0 : PRINT" *** M O D A L   F O R C E S   F O R   M O D E
(";I;") [lbs] ***" :PRINT
12111 LPRINT:LPRINT" *** M O D A L   F O R C E S   F O R   M O D E  (";I;" ) [lb
s] ***" : LPRINT
12112 LPRINT " N ": LPRINT
12114 PRINT " N " : PRINT
12115 FF$ = "##     ##.######^^^^"
12120          FOR J = 1 TO N
12130               PRINT USING FF$ ; J,F(I,J)
12131               LPRINT USING FF$ ; J,F(I,J)
12140          NEXT J
12150          PRINT:PRINT:PRINT:PRINT
12160          PRINT"                    Press any key to continue ..."
12170          A$ = INKEY$: IF A$ = "" THEN GOTO 12170
12180 NEXT I
12190 IF FLAG1 = 1 THEN GOTO 12280
12200 CLS: LOCATE 5,1,0
12210 PRINT" *** D E F L E C T I O N S   A T   M A S S   A T T A C H M E N T   P O
I N T S ***":PRINT:PRINT
12211 LPRINT : LPRINT"** D E F L E C T I O N S   A T   M A S S   A T T A C H M E
N T   P O I N T S **":LPRINT
12215 DD$ = "##.###### "
12220 FOR I = 1 TO N
12230 PRINT"DELTA (";I;") = ";
12231 LPRINT"    DELTA (";I;") = ";
12232 LPRINT USING DD$ ; DEFL(I) ;
12233 LPRINT"in."
12235 PRINT USING DD$ ; DEFL(I) ;
12236 PRINT "in."
12240 NEXT I
12250 PRINT :PRINT:PRINT
12251 LPRINT:LPRINT
12260 PRINT"                         Press any key to continue ..."
12270 A$ = INKEY$ : IF A$ = "" THEN GOTO 12270
12280 CLS : LOCATE 5,1,0
12290 GOTO 18000
```

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```
12300 PRINT " OPTION NOT AVAILABLE YET;===) USE ( Prtsc ) KEY "
12310 FOR I = 1 TO 3000 : NEXT I GOTO 12000
15000 '****************************************************************
15010 '  S U B R O U T I N E  T O  I N P U T  M A S S / M O D E S
15020 '             F R O M  D I S K  F I L E
15030 '****************************************************************
15040 CLS : LOCATE 5,1,0
15050 PRINT" The program has been initialized to allow user input of the":PRINT
15060 PRINT"Mode Shapes,Frequencies, and Masses via an input file.":PRINT
15070 PRINT : PRINT"If you desire one of the other options,":PRINT:PRINT
15080 PRINT"          PRESS (escape key); ......otherwise ==)":PRINT : PRINT
15090 PRINT"                              PRESS (space  bar)  to continue "
15100 A$ = INKEY$ : IF A$ = CHR$(27) GOTO 270
15110 IF A$ <> CHR$(32) GOTO 15100
15120 CLS:LOCATE 5,1,0
15130 INPUT "Enter the dimension of the Mass Matrix ==)  ";N
15140 IF N <= 50 THEN GOTO 15170
15150 PRINT:PRINT:PRINT"***** PROBLEM SIZE IS LIMITED TO 50 DEG OF FREEDOM ****
*"
15160 FOR I = 1 TO 1000 : NEXT I : GOTO 15130
15170 PRINT:PRINT:INPUT"Enter the number of modes you wish to use ==)  ";M
15175 PRINT:PRINT:INPUT"Enter the input file name            ==)  ",FIN$
15180 CLS
15190 '****************************************************************
15200 ' INPUT MASS,FREQ, AND PHI
15210 '****************************************************************
15220 OPEN FIN$ FOR INPUT AS #1
15240 FOR I = 1 TO N
15250   INPUT #1, MASS(I)
15260 NEXT I
15270 FOR I = 1 TO M
15280   INPUT #1, W(I)
15290   W(I) = W(I) * 6.283185
15300 NEXT I
15310 FOR J = 1 TO N
15330   FOR I = 1 TO M
15340        INPUT #1,PHI(I,J)
15350   NEXT I
15360 NEXT J
15370 '****************************************************************
15380 ' OUTPUT MASS, OMEGA, AND PHI
15390 '****************************************************************
15400 LOCATE 5,1,0 : PRINT"MASS MATRIX DIAGONAL ELEMENTS " : PRINT
15401 LPRINT"***** M A S S  D I A G O N A L  E L E M E N T S *****"
15402 LPRINT
15405 MM$ = "##   ##.#####^^^^    "
15410 FOR I = 1 TO N
15420   PRINT USING MM$ ; I,MASS(I)
15421   LPRINT USING MM$ ; I,MASS(I)
15430 NEXT I
15431 PRINT:PRINT"                   ....PRESS ANY KEY TO CONTINUE"
```

```
15432 A$ = INKEY$ : IF A$ = "" THEN GOTO 15432
15434 CLS
15440 PRINT:PRINT:PRINT
15450 PRINT"FREQUENCIES USED IN ANALYSIS  (RPS)":PRINT
15451 LPRINT
15452 LPRINT"***** F R E Q U E N C I E S   U S E D   I N   A N A L Y S I S   (RPS)
***** ":LPRINT
15460 FOR I = 1 TO M
15470   PRINT I;"    ";W(I)
15471   LPRINT I;"     ";W(I)
15480 NEXT I
15481 PRINT:PRINT"                    ....PRESS ANY KEY TO CONTINUE"
15482 A$ = INKEY$ : IF A$ = "" THEN GOTO 15482
15484 CLS
15490 PRINT:PRINT:PRINT
15491 LPRINT:LPRINT
15500 PRINT"MODES USED IN ANALYSIS":PRINT
15501 LPRINT"***** M O D E S   U S E D   I N   A N A L Y S I S *****":LPRINT
15510 K = M : U$ = "##.#####^^^^    "
15520 IF K > 5 THEN GOTO 15600
15530   FOR J = 1 TO N
15540          FOR I = 1 TO M
15550                  PRINT USING U$; PHI(I,J);
15551                  LPRINT USING U$; PHI(I,J);
15560          NEXT I
15570          PRINT " "
15571          LPRINT " "
15580   NEXT J
15590   PRINT:PRINT
15591 LPRINT : LPRINT
15592 PRINT: PRINT"                    ....PRESS ANY KEY TO CONTINUE"
15593 A$ = INKEY$ : IF A$ = "" THEN GOTO 15593
15594 CLS: GOTO 15740
15600   FOR J = 1 TO N
15610          FOR I = 1 TO 5
15620                  PRINT USING U$; PHI(I,J);
15621                  LPRINT USING U$; PHI(I,J);
15630          NEXT I
15640          PRINT " "
15641          LPRINT " "
15650   NEXT J
15660   PRINT:PRINT:LPRINT:LPRINT
15661 PRINT"                    ....PRESS ANY KEY TO CONTINUE"
15662 A$ = INKEY$ : IF A$ = "" THEN GOTO 15662
15663 CLS: PRINT: PRINT
15670   FOR J = 1 TO N
15680          FOR I = 6 TO N
15690                  PRINT USING U$; PHI(I,J);
15691                  LPRINT USING U$; PHI(I,J);
15700          NEXT I
15710          PRINT " "
```

```
15711       LPRINT " "
15720   NEXT J
15730   PRINT:PRINT:LPRINT:LPRINT
15731 PRINT"                    ....PRESS ANY KEY TO CONTINUE"
15732 A$ = INKEY$ : IF A$ = "" THEN GOTO 15732
15734 CLS: PRINT : PRINT
15735 CLOSE #1
15740 '*********************************************************************
15750 ' NORMALIZE MODE SHAPES
15760 '*********************************************************************
15770 FOR I = 1 TO M
15780   BIG = 0!
15790   FOR J = 1 TO N
15800           IF BIG < PHI(I,J) THEN BIG = PHI(I,J)
15810   NEXT J
15820   FOR J = 1 TO N
15830           PHI(I,J) = PHI(I,J)/BIG
15840   NEXT J
15850 NEXT I
15860 '*********************************************************************
15870 ' OUTPUT NORMALIZED MODE SHAPES
15880 '*********************************************************************
15890 PRINT"NORMALIZED MODES USED IN ANALYSIS":PRINT :LPRINT
15891 LPRINT"***** N O R M A L I Z E D  M O D E S  F O R  A N A L Y S I S *****"
15892 LPRINT
15900 K = M
15910 IF K > 5 THEN GOTO 15980
15920   FOR J = 1 TO N
15930           FOR I = 1 TO M
15940                   PRINT USING U$; PHI(I,J);
15941                   LPRINT USING U$;PHI(I,J);
15950           NEXT I
15960           PRINT " "
15961           LPRINT " "
15970   NEXT J
15971 PRINT: PRINT"            ....PRESS ANY KEY TO CONTINUE"
15972 A$ = INKEY$ : IF A$ = "" THEN GOTO 15972
15973 CLS
15980   LPRINT : LPRINT : GOTO 16120
15990   FOR J = 1 TO N
16000           FOR I = 1 TO 5
16010                   PRINT USING U$; PHI(I,J);
16011                   LPRINT USING U$; PHI(I,J);
16020           NEXT I
16030           PRINT " "
16031           LPRINT " "
16040   NEXT J
16050   PRINT:PRINT:LPRINT:LPRINT
16051   PRINT"            ....PRESS ANY KEY TO CONTINUE"
16052 A$ = INKEY$ : IF A$ = "" THEN GOTO 15052
16053 CLS
```

```
16060    FOR J = 1 TO N
16070         FOR I = 6 TO N
16080              PRINT USING U$; PHI(I,J);
16081              LPRINT USING U$; PHI(I,J);
16090         NEXT I
16100         PRINT " "
16101         LPRINT " "
16110    NEXT J
16120    PRINT:PRINT:LPRINT:LPRINT
16121 PRINT"              ....PRESS ANY KEY TO CONTINUE"
16122 A$ = INKEY$ : IF A$ = "" THEN GOTO 16122
16130 CLS : GOSUB 6000
16140 CLS : LOCATE 21,1,0
16150 PRINT
16155 CLS : GOSUB 8000
16160 CLS : GOSUB 8200
16170 CLS : GOSUB 10000
20000 CLS
20010 LOCATE 5,1,0
20020 PRINT"*** YOU MUST FIRST USE THE PROGRAM JACOBI TO SOLVE EIGENVALUE ***"
20030 PRINT"*** PROBLEM.  IT WILL CALCULATE NATURAL FREQUENCIES AND MODE   ***"
20040 PRINT"***   SHAPES THAT CAN THEN BE USED TO RUN THE DDAM PROGRAM.    ***"
20050 PRINT: PRINT: PRINT:
20060 PRINT"      ...... ENTER <F3>JACOBI<RETURN>":PRINT
20070 PRINT"              <F2>"
20080 STOP
25000 CLS:PRINT"*** USER MAY USE OPTION 4 TO INSTALL HIS/HER SUBROUTINE ***"
25010    PRINT"          *** BEGINNING AT LINE 25000.***"
25020 FOR I = 1 TO 5000 : NEXT I : GOTO 270
```

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C. PROGRAM JACOBI - INSTRUCTIONS FOR USE

The following BASIC program may be used as is or modified by the user to solve the Eigenvalue problem once the equations of motion are formulated. It is self explanatory in execution with the exceptions that the A matrix replaces the stiffness matrix and the B matrix replaces the mass matrix. The program only requires that the upper triangle elements of the stiffness matrix be supplied along with the diagonal elements of the mass matrix.

D. PROGRAM JACOBI LISTING (Adapted from ref. 13)

```
4 CLS
5 REM ==CYCLIC JACOBI METHOD==
10 DIM A(10,10), B(10),U(10,10)
19 REM ==INPUT DATA==
20 GOSUB 70
28 REM==INITIALIZE==
30 GOSUB 660
40 GOSUB 980
45 REM ==OUTPUT RESULTS==
50 GOSUB 750
60 GOTO 3000
65 REM ==INPUT DATA==
70 PRINT
80 PRINT " CYCLIC JACOBI METHOD"
160 PRINT
180 PRINT
190 PRINT " ENTER THE SIZE OF PROBLEM (i.e. no. of rows)"
200 PRINT
```

```
210 INPUT "N =    "; N
220 LPRINT "PROBLEM DIMENSION = "; N
230 INPUT "NUMBER OF SIGNIFICANT FIGURES =  "; S1
240 LPRINT
250 PRINT
260 PRINT " ENTER THE UPPER TRIANGULAR ELEMENTS OF MATRIX A ( by columns ):"
270 PRINT
280 LPRINT "UPPER ELEMENTS OF MATRIX A ="
290 LPRINT
320 FOR J = 1 TO N
330 PRINT
340 PRINT " ENTER UPPER PART OF COLUMN "; J
350 PRINT
360 FOR I = 1 TO J
370 PRINT "  A(";I;",";J;") = ";
380 INPUT A(I,J)
381 LPRINT " A(";I;",";J;") = "; A(I,J)
382 LPRINT
390 NEXT I
400 PRINT
440 PRINT
450 NEXT J
460 FOR I = 1 TO N
470 I1 = I - 1
480 FOR J = 1 TO I1
490 A(I,J) = A(J,I)
500 NEXT J
510 NEXT I
520 PRINT
530 PRINT " ENTER ELEMENTS OF DIAGONAL MATRIX B:"
531 LPRINT " ELEMENTS OF DIAGONAL MATRIX B "
532 LPRINT
540 PRINT
570 FOR I = 1 TO N
580 PRINT " B(";I;") = ";
590 INPUT B(I)
591 LPRINT " B(";I;") = ";B(I)
600 NEXT I
610 PRINT
611 LPRINT
650 RETURN
655 REM ==INITIALIZE TOLERANCE AND MAX NO. OF ROTATIONS ==
660 Z = 2 * S1
670 T1 = 1/(10^Z)
680 PRINT
690 CLS: PRINT  "TOLERANCE = ";T1
691 LPRINT "TOLERANCE = ";T1
700 R = 5*N*N
710 R1 = 0
720 T2 = .1
730 N1 = N - 1
```

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```
740 RETURN
746 REM ==OUTPUT EIGENSOLUTION==
750 PRINT
760 PRINT
770 PRINT "SOLUTION"
771 LPRINT
780 PRINT
781 LPRINT
782 LPRINT "*************** SOLUTION ****************"
783 LPRINT
800 PRINT " NUMBER OF ROTATIONS REQUIRED = ";R1
801 LPRINT "NUMBER OF ROTATIONS REQUIRED = ";R1
802 LPRINT
803 LPRINT
810 PRINT
820 PRINT
830 FOR J = 1 TO N
840 PRINT
850 PRINT " EIGENVALUE ";J;" IS ";B(J)
851 LPRINT "EIGENVALUE ";J;" IS ";B(J)
852 LPRINT
853 LPRINT "ITS EIGENVECTOR IS "
860 PRINT
870 PRINT " ITS EIGENVECTOR IS "
880 PRINT
890 FOR I = 1 TO N
900 PRINT U(I,J)
901 LPRINT U(I,J)
902 LPRINT
910 NEXT I
920 PRINT
921 LPRINT
930 PRINT " PRESS SPACE BAR TO CONTINUE "
940 IF INKEY$ = " " THEN 942
941 GOTO 940
942 CLS
950 PRINT
960 NEXT J
970 RETURN
975 REM ==EIGENPROBLEM SOLUTION==
980 GOSUB 1130
985 REM ==PERFORM ONE CYCLE OF ROTATIONS==
990 GOSUB 1290
995 REM == CHECK TOLERANCE ==
1000 IF X1 < T1 THEN 1110
1005 REM == CHECK NO. OF ROTATIONS ==
1010 IF R1 > R THEN 1040
1020 T2 = .1 * X1
1030 GOTO 990
1040 PRINT
1050 PRINT " *** ERROR ***"
```

```
1051 LPRINT "****************** ERROR ******************"
1060 PRINT
1070 PRINT " NO CONVERGENCE ATTAINED"
1071 LPRINT " NO CONVERGENCE ATTAINED "
1080 PRINT
1081 LPRINT
1090 PRINT " WITH ";R1;" ROTATIONS"
1091 LPRINT " WITH ";R1;" ROTATIONS"
1100 END
1110 GOSUB 1830
1120 RETURN
1130 FOR I = 1 TO N
1140 FOR J = 1 TO N
1150 U(I,J) = 0
1160 NEXT J
1170 U(I,I) = 1
1180 NEXT I
1190 FOR I = 1 TO N
1200 B1 = SQR(B(I))
1210 B(I) = 1 / B1
1220 NEXT I
1230 FOR I = 1 TO N
1240 FOR J = 1 TO N
1250 A(I,J) = B(I) * A(I,J) * B(J)
1260 NEXT J
1270 NEXT I
1280 RETURN
1290 X1 = 0
1300 FOR K = 1 TO N1
1310 K1 = K + 1
1320 FOR L = K1 TO N
1330 A1 = A(K,K)
1340 A2 = A(K,L)
1350 A3 = A(L,L)
1360 X = A2 * A2 /(A1 * A3)
1365 REM == CHECK IF ROTATION IS NEEDED ==
1370 IF X > X1 THEN 1390
1380 GOTO 1800
1390  X1 = X
1400 IF X < T2 THEN 1800
1410 R1 = R1 + 1
1415 REM == COMPUTE ANGLE ==
1420 IF A1 = A3 THEN 1470
1430 Z = .5 * (A1 - A3) /A2
1440 Z1 = 1 + 1/ (Z * Z)
1450 T = -Z * (1 + SQR(Z1))
1460 GOTO 1480
1470 T = 1
1480 C = 1 / SQR( 1 + T * T)
1490 S = C * T
1500 S2 = S * S
```

```
1510 C2 = C * C
1520 A(K,L) = 0
1525 REM == TRANSFORM DIAGONAL ELEMENTS ==
1530 A0 = 2 * A2 * C * S
1540 A(K,K) = A1 *C2 + A0 + A3 * S2
1550 A(L,L) = A1 * S2 - A0 + A3 * C2
1555 REM == TRANSFORM OFF DIAGONAL ELEMENTS ==
1560 FOR I = 1 TO N
1570 IF I < K THEN 1600
1580 IF I > K THEN 1640
1590 GOTO 1740
1600 A0 = A(I,K)
1610 A(I,K) = C * A0 + S * A(I,L)
1620 A(I,L) = -S * A0 + C * A(I,L)
1630 GOTO 1740
1640 IF I < L THEN 1670
1650 IF I > L THEN 1710
1660 GOTO 1740
1670 A0 = A(K,I)
1680 A(K,I) = C * A0 + S * A(I,L)
1690 A(I,L) = -S * A0 + C * A(I,L)
1700 GOTO 1740
1710 A0 = A(K,I)
1720 A(K,I) = C * A0 + S * A(L,I)
1730 A(L,I) = -S * A0 + C * A(L,I)
1740 NEXT I
1745 REM == TRANSFORM MATRIX U TO GENERATE EIGENVECTORS ==
1750 FOR I = 1 TO N
1760 U0 = U(I,K)
1770 U(I,K) = C * U0 + S * U(I,L)
1780 U(I,L) = -S * U0 + C * U(I,L)
1790 NEXT I
1800 NEXT L
1810 NEXT K
1820 RETURN
1825 REM == NORMALIZE EIGENVECTORS ==
1830 FOR I = 1 TO N
1840 FOR J = 1 TO N
1850 U(I,J) = U(I,J) * B(I)
1860 NEXT J
1870 NEXT I
1880 FOR I = 1 TO N
1890 B(I) = A(I,I)
1900 NEXT I
1905 REM == ORDER EIGENSOLUTION ==
1910 FOR I = 1 TO N1
1920 I1 = I + 1
1930 Z = B(I)
1940 M = I
1950 FOR J = I1 TO N
1960 IF Z < B(J) THEN 1990
```

```
1970 Z = B(J)
1980 M = J
1990 NEXT J
2000 B(M) = B(I)
2010 B(I) = Z
2020 FOR J = 1 TO N
2030 Z = U(J,I)
2040 U(J,I) = U(J,M)
2050 U(J,M) = Z
2060 NEXT J
2070 NEXT I
2080 RETURN
3000 PRINT " END OF PROGRAM "
3010 END
```

TO DEFLECTION HISTORIES

```
10 '-------------------------------------------------------------------
20 '    PROGRAM ** SIMPS1 ** USED FOR CASE I
30 '    INTEGRATES VELOCITY HISTORY WRT TIME TO OBTAIN DEFLECTIONS
40 '-------------------------------------------------------------------
50 CLS : DIM A$(3)
60 F(1)=0 : F(2)=0 : F(3)=0 : FORM1$=" #.####   " : FORM2$=" ##.######  "
70 INPUT" ENTER THE NAME OF AN INPUT FILE................ ",FILEIN$ : PRINT
80 INPUT" ENTER THE ORDINATES TO INTEGRATE OVER.......... ",NUMBER : PRINT
90 INPUT" ENTER THE SIZE OF THE INTEGRATION INTERVAL...... ",H
100 CLS
110 OPEN FILEIN$ FOR INPUT AS #1 : OPEN "DISPR2.OUT" FOR OUTPUT AS #2
120 '-------------------------------------------------------------------
130 '    USE SIMPSON'S 1/3 RULE TO CALCULATE DEFLECTIONS
140 '-------------------------------------------------------------------
150 INPUT #1,M,TIME(0),VEL11(0),VEL12(0),VEL13(0),VEL61(0),VEL62(0),VEL63(0)
160 FOR I = 1 TO 2
170    INPUT #1,M,TIME(I),VEL11(I),VEL12(I),VEL13(I),VEL61(I),VEL62(I),VEL63(I)
180 NEXT I
190 V1A = VEL61(0) - VEL11(0)
200 V1B = VEL61(1) - VEL11(1)
210 V1C = VEL61(2) - VEL11(2)
220 Q1 = (V1A + 4*V1B + V1C) * H / 3
230 V2A = VEL62(0) - VEL12(0)
240 V2B = VEL62(1) - VEL12(1)
250 V2C = VEL62(2) - VEL12(2)
260 Q2 = (V2A + 4*V2B + V2C) * H / 3
270 V3A = VEL63(0) - VEL13(0)
280 V3B = VEL63(1) - VEL13(1)
290 V3C = VEL63(2) - VEL13(2)
300 Q3 = (V3A + 4*V3B + V3C) * H / 3
310 F(1) = F(1) + Q1
320 F(2) = F(2) + Q2
330 F(3) = F(3) + Q3
340 T = TIME(1) * 1000
350 FOR I = 1 TO 3
360    IF ABS(QMAX(I)) > ABS(F(I)) THEN GOTO 380
370            QMAX(I) = F(I) : TMAX(I) = T
380 NEXT I
390 PRINT #2, " T = ";: PRINT #2, USING FORM1$;T;
400 PRINT #2, "msec    DX = "; : PRINT #2, USING FORM2$;F(1);
410 PRINT #2, "in.    DY = ";:  PRINT #2, USING FORM2$;F(2);
420 PRINT #2, "in.    DZ = ";:  PRINT #2, USING FORM2$;F(3);:PRINT #2,"in."
430 VEL11(0) = VEL11(2) : VEL12(0) = VEL12(2) : VEL13(0) = VEL13(2)
```

```
440 VEL61(0) = VEL61(2) : VEL62(0) = VEL62(2) : VEL63(0) = VEL63(2)
450 IF M + 2 < NUMBER THEN GOTO 160
460 A$(1) = "(X) = " : A$(2) = "(Y) = " : A$(3) = "(Z) = "
470 FOR I = 1 TO 3
480     PRINT #2, "TMAX";A$(I); : PRINT #2, USING FORM1$;TMAX(I);
485     PRINT #2," msec  DMAX";A$(I);: PRINT #2, USING FORM2$;QMAX(I);
486     PRINT #2," in."
490 NEXT I
500 CLOSE #1 : CLOSE #2




10 '----------------------------------------------------------------
20 '   PROGRAM ** SIMPS2 ** USED FOR CASES II AND III
30 '     INTEGRATES VELOCITY HISTORY WRT TIME TO OBTAIN DEFLECTIONS
40 '----------------------------------------------------------------
50 CLS : DIM A$(3)
60 F(1)=0 : F(2)=0 : FORM1$=" ##.####   " : FORM2$=" ##.######  "
70 INPUT" ENTER THE NAME OF AN INPUT FILE................. ",FILEIN$ : PRINT
80 INPUT" ENTER THE ORDINATES TO INTEGRATE OVER........... ",NUMBER : PRINT
90 INPUT" ENTER THE SIZE OF THE INTEGRATION INTERVAL...... ",H
100 CLS
110 OPEN FILEIN$ FOR INPUT AS #1 : OPEN "DISPR2.OUT" FOR OUTPUT AS #2
115 PRINT #2,"H = ";H;" SEC"
120 '----------------------------------------------------------------
130 '    USE SIMPSON'S 1/3 RULE TO CALCULATE DEFLECTIONS
140 '----------------------------------------------------------------
150 INPUT #1,M,TIME(0),VEL12(0),VEL92(0),VEL52(0),VEL112(0),VEL192(0),VEL152(0)
160 FOR I = 1 TO 2
170     INPUT #1,M,TIME(I),VEL12(I),VEL92(I),VEL52(I),VEL112(I),VEL192(I),VEL152(I)
180 NEXT I
190 V1A = (VEL12(0) + VEL92(0))/2 - VEL52(0)
200 V1B = (VEL12(1) + VEL92(1))/2 - VEL52(1)
210 V1C = (VEL12(2) + VEL92(2))/2 - VEL52(2)
220 Q1  = (V1A + 4*V1B + V1C) * H / 3
230 V2A = (VEL112(0) + VEL192(0))/2 - VEL152(0)
240 V2B = (VEL112(1) + VEL192(1))/2 - VEL152(1)
250 V2C = (VEL112(2) + VEL192(2))/2 - VEL152(2)
260 Q2  = (V2A + 4*V2B + V2C) * H / 3
310 F(1) = F(1) + Q1
320 F(2) = F(2) + Q2
340 T   = TIME(1) * 1000
350 FOR I = 1 TO 2
360     IF ABS(QMAX(I)) > ABS(F(I)) THEN GOTO 380
370             QMAX(I) = F(I) : TMAX(I) = T
380 NEXT I
390 PRINT #2, " T = ";: PRINT #2, USING FORM1$;T;
400 PRINT #2, "msec   D(5,Y) = "; : PRINT #2, USING FORM2$;F(1);
```

```
410 PRINT #2, "in.    D(15,Y) = ";:   PRINT #2, USING FORM2$;F(2);
420 PRINT #2, "in."
430 VEL12(0) = VEL12(2) : VEL92(0) = VEL92(2) : VEL52(0) = VEL52(2)
440 VEL112(0) = VEL112(2) : VEL192(0) = VEL192(2) : VEL152(0) = VEL152(2)
450 IF M + 3 < NUMBER THEN GOTO 160
460 A$(1) = "(5,Y) = " : A$(2) = "(15,Y) = "
470 FOR I = 1 TO 2
480     PRINT #2, "TMAX";A$(I); : PRINT #2, USING FORM1$;TMAX(I);
485     PRINT #2," msec  DMAX";A$(I);: PRINT #2, USING FORM2$;DMAX(I);
486     PRINT #2," in."
490 NEXT I
500 CLOSE #1 : CLOSE #2
```

APPENDIX C - TYPICAL CASE I ANALYSIS

As noted in Chapter V, the first step in each analysis was the construction of an appropriate SAPIV model of the equipment substructure under consideration. In this case, the model represents a 1,000 lb valve attached to the free end of a cantilever foundation.

A. SAPIV INPUT DATA FOR CASE I

The following data file was used to generate the modal information for the Case I model [Ref. 10].

HEADING CARD

    CASE 1 -- VALVE ON CANTILEVER FOUNDATION

MASTER CONTROL CARD

    7,1,0,6,1,0,0,0,0,0

NODAL PT DATA

    0,1,1,0,0,1,1,1,0.,0.,0.,1,0.0
    0,2,1,0,0,0,1,1,0.,0.,5.,1,0.0
    0,6,1,0,0,0,1,1,0.,0.,25.,1,0.0
    0,7,1,1,1,1,1,1,10.,0.,10.,0.0

TYPE 2 - 3D BEAM ELEMENTS

    2,5,1,0,1

MATERIAL PROPERTIES

    1,30.0E6,0.3,7.29E-4,0.0

ELEMENT PROPERTY CARD

    1,17.64,0.0,0.0,539.95,333.95,206.0

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```
        0.0,0.0,0.0,0.0
        0.0,0.0,0.0,0.0
        0.0,0.0,0.0,0.0
        0.0,0.0,0.0,0.0
```

BEAM DATA CARDS

```
    1,1,2,7,1,1,0,0,0,0,000000,1
    5,5,6,7,1,1,0,0,0,0,000000,1
```

CONCENTRATED MASS ON FREE END

```
    6,0,2.591,2.591,2.591,0.0,0.0,0.0
    0,0,0.000,0.000,0.000,0.0,0.0,0.0
```

DYNAMIC ANALYSIS CARD (IN ACCORDANCE WITH REF.4

```
    0,0,0,0.0,0.0,0,0.0
    1,0
    1,1,1,1,1,1,1
```

END OF DATA (DUMMY TITLE CARD)
0,0,0,0,0,0,0,0,0,0

   The output from the SAPIV code is not included here but
all the essential information is included in the USLOB code
output.

B. PICRUST INPUT DATA FOR CASE I

   The PICRUST code is used to process the SAPIV output
and calculate influence coefficients corresponding to the
base or support motions of the substructure. Additionally,
connectivity between the hull and foundation is specified
and a substructure file is produced.

   The following input file was used for CASE I:

LIST OPTIONS

```
    1,1,1,1,0,1,1,1,0,0
    0,1,1,1,1,1,0,1,0,0
```

MODAL SPECIFICATION

```
      5,0,0
CONNECTIVITY

      1,5,10
      270

MODES FROM SAPIV INCLUDED IN ANALYSIS

      .1,2,3,4,5
END
```

The output listing from the PICRUST code is not included here but all essential output from these calculations is included in the USLOB output.

C. USLOB INPUT DATA FOR CASE I (1414" STANDOFF)

The following input data was supplied to the USLOB code to specify the parameters for the time integration and associated output. A total of 1201 time steps are specified for the integration interval, each covering an interval of 5.0E-6 seconds. The XXXX parameters denote parameters for eq. 5 which are ommitted due to the sensitivity of this equation.

The following input data correspond to the USLOB output included in this appendix.

```
TIME STEP AND CONTROL CARD FOR INTEGRATION

      1201,1,1,9,11,1,1
EQUATION (5) PARAMETER SPECIFICATION

      5.0E-6,XXXX,1606,0.0
      5000.,XXXX,XXXX,XXXX,XXXX
```

OUTPUT OPTIONS

```
0,1,0,0,0,0,0,0,1,0
0,0,1,1,0,0,0,1,0,0
```

SHELL VELOCITY OUTPUTS AT EACH TIME STEP

```
1,5,10
```

SUBSTRUCTURE VELOCITY OUTPUTS AT EACH TIME STEP

```
6
1,1,1,2,1,3,6,1,6,2,6,3
```
(This notation specifies the x,y,z translations of the
base and tip nodes of the substructure respectively.)

END

D. LISTING - USLOB OUTPUT FOR CASE 1

CASE 1 -- VALVE ON FOUNDATION VERT DISPL

CONTROL PARAMETERS FOR SUBSTRUCTURE   1

NPOINT =   7   NDOF =   18
 NCDOF =   3   NUDOF =   15
 NFREQ =   10   NFACE =   1
NSYMTY =   0   NFORCE =   13

CONNECTION DATA FOR INTERFACE POINTS

    SHL   SUB   X   Y   Z   XX   YY   ZZ LSGPT LFIND   DEGCON
    56   1   1   1   1   0   0   0 5010   27 2.700000E+02
0DEGROT = 9.000000E+01

1EQUATION NUMBERS FOR SUBSTRUCTURE   1

POINT   X   Y   Z   XX   YY   ZZ
    1   1   2   3   0   0   0
    2   4   5   6   0   0   0
    3   7   8   9   0   0   0
    4   10   11   12   0   0   0
    5   13   14   15   0   0   0
    6   16   17   18   0   0   0
    7   0   0   0   0   0   0

FIXED-BASE NATURAL FREQUENCIES FOR SUBSTRUCTURE   1

MODE   FREQ   MODE   FREQ   MODE   FREQ   MODE   FREQ
   1 4.45541E+02   2 1.05485E+03   3 1.34307E+03   4 4.03705E+03
   5 7.60871E+03   6 9.55805E+03   7 1.04549E+04   8 1.21696E+04
   9 1.22840E+04   10 1.80142E+04

1COMPACTED FIXED-BASE MODES FOR SUBSTRUCTURE   1

              1   2   3   4   5
   1   1.9139E-10 -1.2402E-01   9.5490E-10   6.2397E-12   2.4775E-11
   2   3.1568E-20   8.9711E-09   1.2402E-01   1.1183E-12   1.6989E-13
   3 -1.2402E-01 -4.8508E-20   3.7187E-11 -1.4719E+00 -2.3705E+00
   4   3.8186E-18 -2.4745E-01   1.9053E-09   1.0036E-11   3.9865E-11
   5   6.2987E-20   1.7900E-08   2.4745E-01   1.0006E-12   2.7333E-13
   6 -2.4745E-01 -9.6785E-20   5.9702E-11 -2.3685E+00 -1.4497E+00
   7   5.7052E-18 -3.6971E-01   2.8465E-09   9.9000E-12   3.9373E-11
   8   9.4105E-20   2.6743E-08   3.6971E-01   1.7811E-12   2.6992E-13

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```
 9 -3.6971E-01 -1.4460E-19  5.8957E-11 -2.3393E+00  1.4839E+00
10  7.5646E-18 -4.9020E-01  3.7743E-09  5.9093E-12  2.3492E-11
11  1.2478E-19  3.5459E-08  4.9020E-01  1.0677E-12  1.6103E-13
12 -4.9020E-01 -1.9173E-19  3.5172E-11 -1.3957E+00  2.3572E+00
13  9.3000E-18 -6.0036E-01  4.6040E-09 -3.9555E-13 -1.5718E-12
14  1.5485E-19  4.4006E-08  6.0036E-01 -5.9949E-14 -1.0775E-14
15 -6.0036E-01 -2.3794E-19 -2.3536E-12  9.3383E-02 -4.2362E-02


            6          7          8          9         10
 1  1.4719E+00  3.5420E-14  1.2133E-20  1.2095E-12 -2.3785E+00
 2  1.3626E-13  2.2993E-11 -1.4719E+00  6.6535E-13  9.7987E-11
 3  2.4103E-10 -2.3685E+00 -3.3664E-12 -1.4634E+00 -1.8812E-12
 4  2.3685E+00  5.3840E-14  1.5886E-20 -7.6500E-13 -1.4497E+00
 5  2.1925E-13  3.6999E-11 -2.3685E+00  1.8680E-12  5.7223E-11
 6 -1.5016E-10  1.4719E+00  5.4501E-12  2.3693E+00 -3.7449E-12
 7  2.3393E+00  4.9358E-14  1.1252E-20 -4.6836E-12  1.4839E+00
 8  2.1655E-13  3.6543E-11 -2.3393E+00  1.0516E-12 -6.8350E-11
 9 -1.4869E-10  1.4538E+00 -5.4572E-12 -2.3724E+00 -5.6047E-12
10  1.3957E+00  2.7551E-14  4.4918E-21 -6.5906E-12  2.3572E+00
11  1.2920E-13  2.1803E-11 -1.3957E+00  6.2577E-13 -1.0703E-10
13  2.4276E-10 -2.3754E+00  3.3850E-12  1.4715E+00 -7.4239E-12
14 -9.3383E-02 -1.9932E-15 -4.7535E-22 -5.2983E-12 -4.2362E-02
15 -8.6446E-15 -1.4588E-12  9.3383E-02 -4.1996E-14 -7.7491E-12
16 -2.2910E-12  2.2420E-02 -2.3083E-14 -1.0035E-02 -9.2163E-12
```

1SUBSTRUCTURE CONTROL PARAMETERS

```
 SUB  NFREQ  NDOF  NCDOF  NPTS  LOCQ  NEQB NBLOCK NROWFC
  1    10     10     3     7    518    15     1     3
NBLFOR KOLBAR NBLBAR BEGFRQ BEGSBL BEGBAR BEGFOR
  1    254     1      1      1      1      1
```

CONTROL PARAMETERS FOR SOLUTION

```
NTIME = 1201        NEQS =   638
NSKIP =    2       NRECS =   601
NCHRG =    1      NTHETA =    17
NQUAD =    9      NDELTA =    21
NFINE =   11       NQDOT =   264
KOUPLE =   2       NSUBS =     1
```

SOLUTION PARAMETERS

```
TOTALM = 3.541492E+04      AREA = 3.639044E+06
RHOFLU = 9.452160E-05      CFLU = 6.000000E+04
  DELT = 5.000000E-06      TEND = 6.000000E-03
 XLOAD = 8.844880E+02     STOFF = 1.414000E+03
 RLOAD = 1.606000E+03    ORNRAD = 0.
```

DATA FOR EMPIRICAL PRESSURE-TIME HISTORY

WCHRG = 5.000000E+03   SURCUT = XXXXXXXXXXXX
PZMLT = XXXXXXXXXXXX   THMLT = XXXXXXXXXXXX
PZEXP = XXXXXXXXXXXX   THEXP = XXXXXXXXXXXX

1VELOCITY DISTRIBUTION AT SHELL STATION   56   (SEGMENT   5   POINT   10)

STEP	TIME	WDOT(0)	WDOT(90)	WDOT(180)	WDOT(270)
1	0.	0.	0.	0.	0.
3	1.0000E-05	4.9444E-01	7.5446E-02	1.7639E-01	7.5445E-02
5	2.0000E-05	1.8855E+00	2.8722E-01	6.5644E-01	2.8720E-01
7	3.0000E-05	3.8391E+00	5.8420E-01	1.3085E+00	5.8410E-01
9	4.0000E-05	6.1484E+00	9.3465E-01	2.0219E+00	9.3436E-01
11	5.0000E-05	8.6881E+00	1.3193E+00	2.7669E+00	1.3186E+00
13	6.0000E-05	1.1347E+01	1.7214E+00	3.4983E+00	1.7202E+00
15	7.0000E-05	1.4145E+01	2.1416E+00	4.2275E+00	2.1397E+00
17	8.0000E-05	1.7083E+01	2.5792E+00	4.9559E+00	2.5763E+00
19	9.0000E-05	2.0102E+01	3.0265E+00	5.6665E+00	3.0224E+00
21	1.0000E-04	2.3241E+01	3.4895E+00	6.3713E+00	3.4848E+00
23	1.1000E-04	2.6547E+01	3.9697E+00	7.0994E+00	3.9625E+00
25	1.2000E-04	2.9933E+01	4.4593E+00	7.8237E+00	4.4502E+00
27	1.3000E-04	3.3481E+01	4.9651E+00	8.5656E+00	4.9539E+00
29	1.4000E-04	3.7123E+01	5.4786E+00	9.3141E+00	5.4650E+00
31	1.5000E-04	4.0922E+01	6.0054E+00	1.0091E+01	5.9891E+00
33	1.6000E-04	4.4771E+01	6.5359E+00	1.0856E+01	6.5167E+00
35	1.7000E-04	4.8745E+01	7.0707E+00	1.1647E+01	7.0482E+00
37	1.8000E-04	5.2721E+01	7.6048E+00	1.2411E+01	7.5788E+00
39	1.9000E-04	5.6819E+01	8.1394E+00	1.3200E+01	8.1097E+00
41	2.0000E-04	6.0891E+01	8.6690E+00	1.3957E+01	8.6353E+00
43	2.1000E-04	6.5036E+01	9.1899E+00	1.4723E+01	9.1519E+00
45	2.2000E-04	6.9161E+01	9.7044E+00	1.5459E+01	9.6618E+00
47	2.3000E-04	7.3292E+01	1.0209E+01	1.6185E+01	1.0161E+01
49	2.4000E-04	7.7437E+01	1.0700E+01	1.6899E+01	1.0648E+01
51	2.5000E-04	8.1493E+01	1.1180E+01	1.7569E+01	1.1122E+01
53	2.6000E-04	8.5606E+01	1.1643E+01	1.8247E+01	1.1580E+01
55	2.7000E-04	8.9672E+01	1.2097E+01	1.8895E+01	1.2027E+01
57	2.8000E-04	9.3669E+01	1.2528E+01	1.9509E+01	1.2451E+01
59	2.9000E-04	9.7634E+01	1.2918E+01	2.0106E+01	1.2835E+01
61	3.0000E-04	1.0154E+02	1.3301E+01	2.0669E+01	1.3209E+01
63	3.1000E-04	1.0542E+02	1.3669E+01	2.1219E+01	1.3570E+01
65	3.2000E-04	1.0933E+02	1.4026E+01	2.1774E+01	1.3918E+01
67	3.3000E-04	1.1317E+02	1.4379E+01	2.2300E+01	1.4261E+01
69	3.4000E-04	1.1701E+02	1.4712E+01	2.2828E+01	1.4585E+01
71	3.5000E-04	1.2086E+02	1.5034E+01	2.3353E+01	1.4896E+01
73	3.6000E-04	1.2465E+02	1.5354E+01	2.3858E+01	1.5205E+01
75	3.7000E-04	1.2846E+02	1.5655E+01	2.4379E+01	1.5494E+01
77	3.8000E-04	1.3226E+02	1.5940E+01	2.4892E+01	1.5767E+01

79	3.9000E-04	1.3599E+02	1.6222E+01	2.5382E+01	1.6036E+01
81	4.0000E-04	1.3974E+02	1.6490E+01	2.5884E+01	1.6291E+01
83	4.1000E-04	1.4349E+02	1.6740E+01	2.6395E+01	1.6526E+01
85	4.2000E-04	1.4719E+02	1.6987E+01	2.6885E+01	1.6759E+01
87	4.3000E-04	1.5086E+02	1.7222E+01	2.7371E+01	1.6979E+01
89	4.4000E-04	1.5454E+02	1.7432E+01	2.7866E+01	1.7174E+01
91	4.5000E-04	1.5817E+02	1.7639E+01	2.8350E+01	1.7365E+01
93	4.6000E-04	1.6175E+02	1.7843E+01	2.8822E+01	1.7553E+01
95	4.7000E-04	1.6533E+02	1.8017E+01	2.9304E+01	1.7710E+01
97	4.8000E-04	1.6888E+02	1.8180E+01	2.9778E+01	1.7856E+01
99	4.9000E-04	1.7237E+02	1.8342E+01	3.0233E+01	1.8000E+01
101	5.0000E-04	1.7580E+02	1.8487E+01	3.0677E+01	1.8127E+01
103	5.1000E-04	1.7920E+02	1.8601E+01	3.1125E+01	1.8223E+01
105	5.2000E-04	1.8255E+02	1.8714E+01	3.1558E+01	1.8317E+01
107	5.3000E-04	1.8585E+02	1.8824E+01	3.1964E+01	1.8408E+01
109	5.4000E-04	1.8910E+02	1.8900E+01	3.2371E+01	1.8463E+01
111	5.5000E-04	1.9229E+02	1.8957E+01	3.2765E+01	1.8501E+01
113	5.6000E-04	1.9540E+02	1.9013E+01	3.3136E+01	1.8537E+01
115	5.7000E-04	1.9845E+02	1.9063E+01	3.3489E+01	1.8565E+01
117	5.8000E-04	2.0147E+02	1.9071E+01	3.3847E+01	1.8552E+01
119	5.9000E-04	2.0442E+02	1.9074E+01	3.4182E+01	1.8533E+01
121	6.0000E-04	2.0730E+02	1.9076E+01	3.4496E+01	1.8512E+01
123	6.1000E-04	2.1010E+02	1.9057E+01	3.4789E+01	1.8471E+01
125	6.2000E-04	2.1283E+02	1.8995E+01	3.5074E+01	1.8386E+01
127	6.3000E-04	2.1558E+02	1.8932E+01	3.5335E+01	1.8300E+01
129	6.4000E-04	2.1811E+02	1.8869E+01	3.5583E+01	1.8213E+01
131	6.5000E-04	2.2067E+02	1.8790E+01	3.5823E+01	1.8110E+01
133	6.6000E-04	2.2317E+02	1.8681E+01	3.6056E+01	1.7978E+01
135	6.7000E-04	2.2563E+02	1.8572E+01	3.6277E+01	1.7844E+01
137	6.8000E-04	2.2805E+02	1.8463E+01	3.6484E+01	1.7711E+01
139	6.9000E-04	2.3041E+02	1.8340E+01	3.6682E+01	1.7564E+01
141	7.0000E-04	2.3271E+02	1.8189E+01	3.6873E+01	1.7389E+01
143	7.1000E-04	2.3497E+02	1.8035E+01	3.7054E+01	1.7211E+01
145	7.2000E-04	2.3719E+02	1.7882E+01	3.7222E+01	1.7034E+01
147	7.3000E-04	2.3936E+02	1.7723E+01	3.7379E+01	1.6851E+01
149	7.4000E-04	2.4147E+02	1.7531E+01	3.7534E+01	1.6635E+01
151	7.5000E-04	2.4354E+02	1.7336E+01	3.7676E+01	1.6415E+01
153	7.6000E-04	2.4558E+02	1.7146E+01	3.7806E+01	1.6201E+01
155	7.7000E-04	2.4757E+02	1.6961E+01	3.7924E+01	1.5993E+01
157	7.8000E-04	2.4950E+02	1.6736E+01	3.8042E+01	1.5744E+01
159	7.9000E-04	2.5139E+02	1.6504E+01	3.8147E+01	1.5489E+01
161	8.0000E-04	2.5325E+02	1.6279E+01	3.8242E+01	1.5240E+01
163	8.1000E-04	2.5508E+02	1.6062E+01	3.8326E+01	1.5001E+01
165	8.2000E-04	2.5685E+02	1.5889E+01	3.8407E+01	1.4725E+01
167	8.3000E-04	2.5857E+02	1.5546E+01	3.8481E+01	1.4440E+01
169	8.4000E-04	2.6026E+02	1.5290E+01	3.8542E+01	1.4161E+01
171	8.5000E-04	2.6193E+02	1.5039E+01	3.8594E+01	1.3888E+01
173	8.6000E-04	2.6355E+02	1.4778E+01	3.8648E+01	1.3606E+01
175	8.7000E-04	2.6510E+02	1.4488E+01	3.8680E+01	1.3294E+01
177	8.8000E-04	2.6663E+02	1.4200E+01	3.8710E+01	1.2985E+01
179	8.9000E-04	2.6813E+02	1.3917E+01	3.8730E+01	1.2682E+01

181	9.0000E-04	2.6961E+02	1.3643E+01	3.8739E+01	1.2388E+01
183	9.1000E-04	2.7102E+02	1.3335E+01	3.8746E+01	1.2060E+01
185	9.2000E-04	2.7238E+02	1.3019E+01	3.8746E+01	1.1725E+01
187	9.3000E-04	2.7372E+02	1.2709E+01	3.8734E+01	1.1397E+01
189	9.4000E-04	2.7505E+02	1.2406E+01	3.8713E+01	1.1077E+01
191	9.5000E-04	2.7633E+02	1.2100E+01	3.8686E+01	1.0754E+01
193	9.6000E-04	2.7755E+02	1.1765E+01	3.8652E+01	1.0403E+01
195	9.7000E-04	2.7873E+02	1.1429E+01	3.8608E+01	1.0052E+01
197	9.8000E-04	2.7991E+02	1.1100E+01	3.8552E+01	9.7097E+00
199	9.9000E-04	2.8106E+02	1.0778E+01	3.8489E+01	9.3739E+00
201	1.0000E-03	2.8216E+02	1.0442E+01	3.8421E+01	9.0253E+00
203	1.0100E-03	2.8320E+02	1.0089E+01	3.8346E+01	8.6604E+00
205	1.0200E-03	2.8423E+02	9.7388E+00	3.8257E+01	8.2991E+00
207	1.0300E-03	2.8524E+02	9.3938E+00	3.8163E+01	7.9440E+00
209	1.0400E-03	2.8623E+02	9.0548E+00	3.8061E+01	7.5959E+00
211	1.0500E-03	2.8715E+02	8.7064E+00	3.7956E+01	7.2392E+00
213	1.0600E-03	2.8802E+02	8.3494E+00	3.7849E+01	6.8749E+00
215	1.0700E-03	2.8887E+02	7.9933E+00	3.7734E+01	6.5125E+00
217	1.0800E-03	2.8971E+02	7.6462E+00	3.7611E+01	6.1599E+00
219	1.0900E-03	2.9054E+02	7.3036E+00	3.7480E+01	5.8128E+00
221	1.1000E-03	2.9130E+02	6.9413E+00	3.7345E+01	5.4468E+00
223	1.1100E-03	2.9201E+02	6.5667E+00	3.7206E+01	5.0696E+00
225	1.1200E-03	2.9272E+02	6.1998E+00	3.7058E+01	4.7009E+00
227	1.1300E-03	2.9342E+02	5.8414E+00	3.6898E+01	4.3419E+00
229	1.1400E-03	2.9411E+02	5.4887E+00	3.6729E+01	3.9896E+00
231	1.1500E-03	2.9473E+02	5.1168E+00	3.6555E+01	3.6193E+00
233	1.1600E-03	2.9531E+02	4.7374E+00	3.6375E+01	3.2426E+00
235	1.1700E-03	2.9589E+02	4.3669E+00	3.6185E+01	2.8762E+00
237	1.1800E-03	2.9646E+02	4.0038E+00	3.5985E+01	2.5183E+00
239	1.1900E-03	2.9703E+02	3.6475E+00	3.5777E+01	2.1684E+00
241	1.2000E-03	2.9752E+02	3.2711E+00	3.5571E+01	1.7998E+00
243	1.2100E-03	2.9796E+02	2.8911E+00	3.5359E+01	1.4288E+00
245	1.2200E-03	2.9841E+02	2.5193E+00	3.5138E+01	1.0673E+00
247	1.2300E-03	2.9886E+02	2.1528E+00	3.4909E+01	7.1232E-01
249	1.2400E-03	2.9929E+02	1.7896E+00	3.4676E+01	3.6192E-01
251	1.2500E-03	2.9966E+02	1.4168E+00	3.4442E+01	3.2035E-03
253	1.2600E-03	2.9999E+02	1.0388E+00	3.4205E+01	-3.5943E-01
255	1.2700E-03	3.0031E+02	6.6715E-01	3.3959E+01	-7.1455E-01
257	1.2800E-03	3.0063E+02	2.9858E-01	3.3787E+01	-1.0653E+00
259	1.2900E-03	3.0094E+02	-6.5765E-02	3.3451E+01	-1.4107E+00
261	1.3000E-03	3.0121E+02	-4.3242E-01	3.3190E+01	-1.7571E+00
263	1.3100E-03	3.0142E+02	-8.0686E-01	3.2925E+01	-2.1101E+00
265	1.3200E-03	3.0164E+02	-1.1766E+00	3.2647E+01	-2.4572E+00
267	1.3300E-03	3.0185E+02	-1.5432E+00	3.2363E+01	-2.8000E+00
269	1.3400E-03	3.0206E+02	-1.9046E+00	3.2070E+01	-3.1364E+00
271	1.3500E-03	3.0225E+02	-2.2646E+00	3.1774E+01	-3.4782E+00
273	1.3600E-03	3.0236E+02	-2.6320E+00	3.1478E+01	-3.8104E+00
275	1.3700E-03	3.0246E+02	-2.9962E+00	3.1175E+01	-4.1462E+00
277	1.3800E-03	3.0256E+02	-3.3570E+00	3.0869E+01	-4.4775E+00
279	1.3900E-03	3.0267E+02	-3.7125E+00	3.0553E+01	-4.8023E+00
281	1.4000E-03	3.0278E+02	-4.0645E+00	3.0233E+01	-5.1225E+00

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283  1.4100E-03  3.0280E+02 -4.4214E+00  2.9917E+01 -5.4463E+00
285  1.4200E-03  3.0280E+02 -4.7756E+00  2.9599E+01 -5.7662E+00
287  1.4300E-03  3.0279E+02 -5.1262E+00  2.9276E+01 -6.0813E+00
289  1.4400E-03  3.0280E+02 -5.4737E+00  2.8944E+01 -6.3920E+00
291  1.4500E-03  3.0281E+02 -5.8180E+00  2.8606E+01 -6.6982E+00
293  1.4600E-03  3.0277E+02 -6.1611E+00  2.8268E+01 -7.0021E+00
295  1.4700E-03  3.0267E+02 -6.5018E+00  2.7936E+01 -7.3024E+00
297  1.4800E-03  3.0257E+02 -6.8409E+00  2.7599E+01 -7.5999E+00
299  1.4900E-03  3.0247E+02 -7.1776E+00  2.7255E+01 -7.8941E+00
301  1.5000E-03  3.0239E+02 -7.5121E+00  2.6903E+01 -8.1850E+00
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(This history is abbreviated for illustrative purposes.)

1VELOCITY DISTRIBUTION ALONG SUBSTRUCTURE   1

STEP	TIME	VEL(1,1)	VEL(1,2)	VEL(1,3)	VEL(6,1)	VEL(6,2)	VEL(6,3)
1	0.	0.	0.	0.	0.	0.	0.
3	1.0000E-05	-7.6928E-04	-6.4008E-03	7.5445E-02	6.6872E-07	-1.9765E-05	-4.3588E-14
5	2.0000E-05	-3.6167E-03	-2.0700E-02	2.8720E-01	1.9028E-06	-3.3974E-05	1.4181E-12
7	3.0000E-05	-8.8040E-03	-3.3246E-02	5.8410E-01	1.6589E-06	1.2365E-05	3.8135E-10
9	4.0000E-05	-1.6429E-02	-3.7045E-02	9.3436E-01	-3.5152E-08	4.4999E-05	1.3005E-08
11	5.0000E-05	-2.6541E-02	-2.6866E-02	1.3186E+00	-4.3943E-06	-1.6797E-04	1.8281E-07
13	6.0000E-05	-3.8720E-02	3.0282E-04	1.7202E+00	-2.8589E-05	-9.1328E-04	1.5070E-06
15	7.0000E-05	-5.2809E-02	4.4051E-02	2.1397E+00	-1.2167E-04	-2.3440E-03	8.6295E-06
17	8.0000E-05	-6.8819E-02	1.0709E-01	2.5763E+00	-3.7008E-04	-4.2651E-03	3.7798E-05
19	9.0000E-05	-8.6191E-02	1.8835E-01	3.0224E+00	-8.8620E-04	-6.0883E-03	1.3459E-04
21	1.0000E-04	-1.0522E-01	2.9143E-01	3.4840E+00	-1.7841E-03	-6.8775E-03	4.0597E-04
23	1.1000E-04	-1.2514E-01	4.1250E-01	3.9625E+00	-3.1660E-03	-5.5941E-03	1.0680E-03
25	1.2000E-04	-1.4552E-01	5.5122E-01	4.4502E+00	-5.1171E-03	-1.2343E-03	2.5041E-03
27	1.3000E-04	-1.6745E-01	7.1056E-01	4.9539E+00	-7.7110E-03	7.0835E-03	5.3195E-03
29	1.4000E-04	-1.9027E-01	8.8589E-01	5.4650E+00	-1.1017E-02	2.0120E-02	1.0372E-02
31	1.5000E-04	-2.1381E-01	1.0795E+00	5.9891E+00	-1.5895E-02	3.8730E-02	1.8757E-02
33	1.6000E-04	-2.3783E-01	1.2921E+00	6.5167E+00	-1.9996E-02	6.3995E-02	3.1738E-02
35	1.7000E-04	-2.6205E-01	1.5173E+00	7.0482E+00	-2.5775E-02	9.7299E-02	5.0620E-02
37	1.8000E-04	-2.8685E-01	1.7626E+00	7.5788E+00	-3.2514E-02	1.4036E-01	7.6605E-02
39	1.9000E-04	-3.1149E-01	2.0222E+00	8.1097E+00	-4.0329E-02	1.9492E-01	1.1065E-01
41	2.0000E-04	-3.3681E-01	2.2970E+00	8.6353E+00	-4.9349E-02	2.6265E-01	1.5337E-01
43	2.1000E-04	-3.6129E-01	2.5879E+00	9.1519E+00	-5.9691E-02	3.4499E-01	2.0586E-01
45	2.2000E-04	-3.8600E-01	2.8949E+00	9.6618E+00	-7.1427E-02	4.4315E-01	2.6573E-01
47	2.3000E-04	-4.1029E-01	3.2141E+00	1.0161E+01	-8.4601E-02	5.5824E-01	3.3527E-01
49	2.4000E-04	-4.3351E-01	3.5481E+00	1.0648E+01	-9.9240E-02	6.9154E-01	4.1357E-01
51	2.5000E-04	-4.5582E-01	3.8942E+00	1.1122E+01	-1.1536E-01	8.4451E-01	5.0061E-01
53	2.6000E-04	-4.7767E-01	4.2550E+00	1.1580E+01	-1.3297E-01	1.0188E+00	5.9653E-01
55	2.7000E-04	-4.9885E-01	4.6265E+00	1.2027E+01	-1.5208E-01	1.2161E+00	7.0155E-01
57	2.8000E-04	-5.1832E-01	5.0121E+00	1.2451E+01	-1.7266E-01	1.4379E+00	8.1594E-01
59	2.9000E-04	-5.3628E-01	5.4117E+00	1.2835E+01	-1.9473E-01	1.6854E+00	9.3985E-01
61	3.0000E-04	-5.5399E-01	5.8235E+00	1.3209E+01	-2.1829E-01	1.9593E+00	1.0733E+00
63	3.1000E-04	-5.7035E-01	6.2440E+00	1.3570E+01	-2.4339E-01	2.2603E+00	1.2163E+00
65	3.2000E-04	-5.8550E-01	6.6781E+00	1.3918E+01	-2.7002E-01	2.5890E+00	1.3685E+00
67	3.3000E-04	-5.9947E-01	7.1191E+00	1.4261E+01	-2.9812E-01	2.9461E+00	1.5299E+00
69	3.4000E-04	-6.1224E-01	7.5694E+00	1.4585E+01	-3.2760E-01	3.3327E+00	1.7001E+00

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 71  3.5000E-04 -6.2460E-01  8.0300E+00  1.4896E+01 -3.5835E-01  3.7494E+00  1.0791E+00
 73  3.6000E-04 -6.3510E-01  8.4948E+00  1.5205E+01 -3.9026E-01  4.1969E+00  2.0670E+00
 75  3.7000E-04 -6.4496E-01  8.9686E+00  1.5494E+01 -4.2323E-01  4.6753E+00  2.2639E+00
 77  3.8000E-04 -6.5416E-01  9.4509E+00  1.5767E+01 -4.5715E-01  5.1844E+00  2.4700E+00
 79  3.9000E-04 -6.6229E-01  9.9375E+00  1.6036E+01 -4.9189E-01  5.7236E+00  2.6857E+00
 81  4.0000E-04 -6.7034E-01  1.0431E+01  1.6291E+01 -5.2736E-01  6.2922E+00  2.9112E+00
 83  4.1000E-04 -6.7756E-01  1.0931E+01  1.6526E+01 -5.6347E-01  6.8896E+00  3.1470E+00
 85  4.2000E-04 -6.8457E-01  1.1437E+01  1.6759E+01 -6.0013E-01  7.5155E+00  3.3937E+00
 87  4.3000E-04 -6.9093E-01  1.1948E+01  1.6979E+01 -6.3723E-01  8.1693E+00  3.6518E+00
 89  4.4000E-04 -6.9747E-01  1.2465E+01  1.7174E+01 -6.7464E-01  8.8503E+00  3.9219E+00
 91  4.5000E-04 -7.0376E-01  1.2989E+01  1.7365E+01 -7.1217E-01  9.5574E+00  4.2043E+00
 93  4.6000E-04 -7.1020E-01  1.3512E+01  1.7553E+01 -7.4965E-01  1.0289E+01  4.4993E+00
 95  4.7000E-04 -7.1622E-01  1.4043E+01  1.7710E+01 -7.8691E-01  1.1044E+01  4.8069E+00
 97  4.8000E-04 -7.2251E-01  1.4580E+01  1.7856E+01 -8.2381E-01  1.1819E+01  5.1266E+00
 99  4.9000E-04 -7.2891E-01  1.5118E+01  1.8000E+01 -8.6022E-01  1.2614E+01  5.4580E+00
101  5.0000E-04 -7.3577E-01  1.5659E+01  1.8127E+01 -8.9602E-01  1.3426E+01  5.8002E+00
103  5.1000E-04 -7.4298E-01  1.6208E+01  1.8223E+01 -9.3109E-01  1.4253E+01  6.1527E+00
105  5.2000E-04 -7.5094E-01  1.6760E+01  1.8317E+01 -9.6536E-01  1.5095E+01  6.5146E+00
107  5.3000E-04 -7.5834E-01  1.7311E+01  1.8400E+01 -9.9872E-01  1.5950E+01  6.8856E+00
109  5.4000E-04 -7.6640E-01  1.7871E+01  1.8463E+01 -1.0311E+00  1.6814E+01  7.2652E+00
111  5.5000E-04 -7.7556E-01  1.8433E+01  1.8501E+01 -1.0623E+00  1.7686E+01  7.6533E+00
113  5.6000E-04 -7.8511E-01  1.8995E+01  1.8537E+01 -1.0923E+00  1.8562E+01  8.0496E+00
115  5.7000E-04 -7.9475E-01  1.9559E+01  1.8565E+01 -1.1209E+00  1.9442E+01  8.4538E+00
117  5.8000E-04 -8.0490E-01  2.0129E+01  1.8552E+01 -1.1480E+00  2.0321E+01  8.8657E+00
119  5.9000E-04 -8.1562E-01  2.0702E+01  1.8533E+01 -1.1735E+00  2.1199E+01  9.2848E+00
121  6.0000E-04 -8.2643E-01  2.1275E+01  1.8512E+01 -1.1974E+00  2.2074E+01  9.7105E+00
123  6.1000E-04 -8.3804E-01  2.1851E+01  1.8471E+01 -1.2197E+00  2.2944E+01  1.0142E+01
125  6.2000E-04 -8.5026E-01  2.2436E+01  1.8386E+01 -1.2403E+00  2.3806E+01  1.0579E+01
127  6.3000E-04 -8.6205E-01  2.3023E+01  1.8300E+01 -1.2592E+00  2.4659E+01  1.1021E+01
129  6.4000E-04 -8.7428E-01  2.3608E+01  1.8213E+01 -1.2764E+00  2.5499E+01  1.1468E+01
131  6.5000E-04 -8.8701E-01  2.4194E+01  1.8118E+01 -1.2919E+00  2.6325E+01  1.1919E+01
133  6.6000E-04 -8.9966E-01  2.4788E+01  1.7978E+01 -1.3057E+00  2.7136E+01  1.2375E+01
135  6.7000E-04 -9.1225E-01  2.5388E+01  1.7844E+01 -1.3176E+00  2.7930E+01  1.2836E+01
137  6.8000E-04 -9.2519E-01  2.5971E+01  1.7711E+01 -1.3277E+00  2.8706E+01  1.3302E+01
139  6.9000E-04 -9.3799E-01  2.6562E+01  1.7564E+01 -1.3360E+00  2.9464E+01  1.3774E+01
141  7.0000E-04 -9.5074E-01  2.7162E+01  1.7389E+01 -1.3425E+00  3.0201E+01  1.4250E+01
143  7.1000E-04 -9.6374E-01  2.7760E+01  1.7211E+01 -1.3473E+00  3.0916E+01  1.4730E+01
145  7.2000E-04 -9.7703E-01  2.8354E+01  1.7034E+01 -1.3504E+00  3.1608E+01  1.5215E+01
147  7.3000E-04 -9.8930E-01  2.8950E+01  1.6851E+01 -1.3519E+00  3.2277E+01  1.5703E+01
149  7.4000E-04 -1.0021E+00  2.9552E+01  1.6635E+01 -1.3518E+00  3.2922E+01  1.6193E+01
151  7.5000E-04 -1.0150E+00  3.0155E+01  1.6415E+01 -1.3502E+00  3.3543E+01  1.6685E+01
153  7.6000E-04 -1.0277E+00  3.0755E+01  1.6201E+01 -1.3472E+00  3.4140E+01  1.7177E+01
155  7.7000E-04 -1.0396E+00  3.1352E+01  1.5993E+01 -1.3429E+00  3.4713E+01  1.7669E+01
157  7.8000E-04 -1.0519E+00  3.1957E+01  1.5744E+01 -1.3371E+00  3.5263E+01  1.8159E+01
159  7.9000E-04 -1.0647E+00  3.2563E+01  1.5489E+01 -1.3301E+00  3.5789E+01  1.8647E+01
161  8.0000E-04 -1.0765E+00  3.3167E+01  1.5240E+01 -1.3219E+00  3.6292E+01  1.9131E+01
163  8.1000E-04 -1.0881E+00  3.3766E+01  1.5001E+01 -1.3125E+00  3.6772E+01  1.9611E+01
165  8.2000E-04 -1.1002E+00  3.4372E+01  1.4725E+01 -1.3021E+00  3.7231E+01  2.0085E+01
167  8.3000E-04 -1.1121E+00  3.4980E+01  1.4440E+01 -1.2909E+00  3.7669E+01  2.0555E+01
169  8.4000E-04 -1.1235E+00  3.5586E+01  1.4161E+01 -1.2789E+00  3.8088E+01  2.1019E+01
171  8.5000E-04 -1.1348E+00  3.6189E+01  1.3888E+01 -1.2664E+00  3.8490E+01  2.1477E+01
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173  8.6000E-04 -1.1460E+00  3.6790E+01  1.3606E+01 -1.2532E+00  3.8875E+01  2.1929E+01
175  8.7000E-04 -1.1572E+00  3.7400E+01  1.3294E+01 -1.2397E+00  3.9247E+01  2.2374E+01
177  8.8000E-04 -1.1679E+00  3.8008E+01  1.2985E+01 -1.2257E+00  3.9605E+01  2.2811E+01
179  8.9000E-04 -1.1785E+00  3.8613E+01  1.2682E+01 -1.2115E+00  3.9951E+01  2.3248E+01
181  9.0000E-04 -1.1892E+00  3.9213E+01  1.2388E+01 -1.1971E+00  4.0287E+01  2.3660E+01
183  9.1000E-04 -1.1993E+00  3.9821E+01  1.2060E+01 -1.1826E+00  4.0615E+01  2.4070E+01
185  9.2000E-04 -1.2090E+00  4.0430E+01  1.1725E+01 -1.1681E+00  4.0937E+01  2.4471E+01
187  9.3000E-04 -1.2193E+00  4.1038E+01  1.1397E+01 -1.1539E+00  4.1257E+01  2.4862E+01
189  9.4000E-04 -1.2291E+00  4.1641E+01  1.1077E+01 -1.1399E+00  4.1575E+01  2.5245E+01
191  9.5000E-04 -1.2383E+00  4.2240E+01  1.0754E+01 -1.1264E+00  4.1894E+01  2.5617E+01
193  9.6000E-04 -1.2473E+00  4.2849E+01  1.0483E+01 -1.1135E+00  4.2216E+01  2.5980E+01
195  9.7000E-04 -1.2564E+00  4.3457E+01  1.0052E+01 -1.1012E+00  4.2542E+01  2.6333E+01
197  9.8000E-04 -1.2655E+00  4.4062E+01  9.7097E+00 -1.0895E+00  4.2873E+01  2.6676E+01
199  9.9000E-04 -1.2737E+00  4.4661E+01  9.3739E+00 -1.0786E+00  4.3213E+01  2.7007E+01
201  1.0000E-03 -1.2818E+00  4.5263E+01  9.0253E+00 -1.0686E+00  4.3563E+01  2.7325E+01
203  1.0100E-03 -1.2898E+00  4.5870E+01  8.6604E+00 -1.0594E+00  4.3926E+01  2.7629E+01
205  1.0200E-03 -1.2982E+00  4.6477E+01  8.2991E+00 -1.0512E+00  4.4303E+01  2.7918E+01
207  1.0300E-03 -1.3057E+00  4.7079E+01  7.9440E+00 -1.0441E+00  4.4696E+01  2.8192E+01
209  1.0400E-03 -1.3129E+00  4.7676E+01  7.5959E+00 -1.0381E+00  4.5105E+01  2.8448E+01
211  1.0500E-03 -1.3200E+00  4.8279E+01  7.2392E+00 -1.0334E+00  4.5533E+01  2.8687E+01
213  1.0600E-03 -1.3272E+00  4.8885E+01  6.8749E+00 -1.0300E+00  4.5980E+01  2.8908E+01
215  1.0700E-03 -1.3338E+00  4.9490E+01  6.5125E+00 -1.0280E+00  4.6447E+01  2.9111E+01
217  1.0800E-03 -1.3399E+00  5.0089E+01  6.1599E+00 -1.0273E+00  4.6936E+01  2.9294E+01
219  1.0900E-03 -1.3460E+00  5.0684E+01  5.8128E+00 -1.0280E+00  4.7447E+01  2.9458E+01
221  1.1000E-03 -1.3520E+00  5.1285E+01  5.4468E+00 -1.0301E+00  4.7982E+01  2.9602E+01
223  1.1100E-03 -1.3579E+00  5.1889E+01  5.0696E+00 -1.0335E+00  4.8541E+01  2.9727E+01
225  1.1200E-03 -1.3633E+00  5.2490E+01  4.7009E+00 -1.0384E+00  4.9124E+01  2.9831E+01
227  1.1300E-03 -1.3683E+00  5.3085E+01  4.3419E+00 -1.0446E+00  4.9731E+01  2.9916E+01
229  1.1400E-03 -1.3730E+00  5.3676E+01  3.9896E+00 -1.0522E+00  5.0360E+01  2.9980E+01
231  1.1500E-03 -1.3777E+00  5.4274E+01  3.6193E+00 -1.0613E+00  5.1014E+01  3.0024E+01
233  1.1600E-03 -1.3820E+00  5.4876E+01  3.2426E+00 -1.0719E+00  5.1690E+01  3.0048E+01
235  1.1700E-03 -1.3860E+00  5.5473E+01  2.8762E+00 -1.0838E+00  5.2389E+01  3.0050E+01
237  1.1800E-03 -1.3900E+00  5.6066E+01  2.5183E+00 -1.0971E+00  5.3111E+01  3.0031E+01
239  1.1900E-03 -1.3936E+00  5.6654E+01  2.1684E+00 -1.1118E+00  5.3853E+01  2.9992E+01
241  1.2000E-03 -1.3969E+00  5.7248E+01  1.7998E+00 -1.1276E+00  5.4617E+01  2.9931E+01
243  1.2100E-03 -1.4000E+00  5.7844E+01  1.4288E+00 -1.1445E+00  5.5398E+01  2.9850E+01
245  1.2200E-03 -1.4030E+00  5.8437E+01  1.0673E+00 -1.1626E+00  5.6197E+01  2.9749E+01
247  1.2300E-03 -1.4058E+00  5.9025E+01  7.1232E-01 -1.1817E+00  5.7012E+01  2.9627E+01
249  1.2400E-03 -1.4080E+00  5.9606E+01  3.6192E-01 -1.2017E+00  5.7840E+01  2.9484E+01
251  1.2500E-03 -1.4100E+00  6.0192E+01  3.2035E-03 -1.2227E+00  5.8681E+01  2.9320E+01
253  1.2600E-03 -1.4119E+00  6.0781E+01 -3.5943E-01 -1.2445E+00  5.9533E+01  2.9134E+01
255  1.2700E-03 -1.4137E+00  6.1368E+01 -7.1455E-01 -1.2671E+00  6.0395E+01  2.8925E+01
257  1.2800E-03 -1.4151E+00  6.1950E+01 -1.0653E+00 -1.2905E+00  6.1264E+01  2.8692E+01
259  1.2900E-03 -1.4160E+00  6.2524E+01 -1.4107E+00 -1.3144E+00  6.2138E+01  2.8435E+01
261  1.3000E-03 -1.4166E+00  6.3101E+01 -1.7571E+00 -1.3387E+00  6.3014E+01  2.8153E+01
263  1.3100E-03 -1.4174E+00  6.3686E+01 -2.1101E+00 -1.3633E+00  6.3890E+01  2.7845E+01
265  1.3200E-03 -1.4178E+00  6.4268E+01 -2.4572E+00 -1.3882E+00  6.4765E+01  2.7512E+01
267  1.3300E-03 -1.4179E+00  6.4846E+01 -2.8000E+00 -1.4131E+00  6.5636E+01  2.7154E+01
269  1.3400E-03 -1.4175E+00  6.5419E+01 -3.1364E+00 -1.4380E+00  6.6501E+01  2.6772E+01
271  1.3500E-03 -1.4168E+00  6.5990E+01 -3.4702E+00 -1.4629E+00  6.7360E+01  2.6365E+01
273  1.3600E-03 -1.4163E+00  6.6568E+01 -3.8104E+00 -1.4875E+00  6.8209E+01  2.5933E+01
```

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275  1.3700E-03 -1.4156E+00  6.7146E+01 -4.1462E+00 -1.5120E+00  6.9047E+01  2.5478E+01
277  1.3800E-03 -1.4142E+00  6.7718E+01 -4.4775E+00 -1.5360E+00  6.9870E+01  2.5000E+01
279  1.3900E-03 -1.4128E+00  6.8285E+01 -4.8023E+00 -1.5596E+00  7.0678E+01  2.4498E+01
281  1.4000E-03 -1.4109E+00  6.8845E+01 -5.1225E+00 -1.5825E+00  7.1469E+01  2.3973E+01
283  1.4100E-03 -1.4091E+00  6.9415E+01 -5.4463E+00 -1.6046E+00  7.2241E+01  2.3426E+01
285  1.4200E-03 -1.4070E+00  6.9984E+01 -5.7662E+00 -1.6259E+00  7.2993E+01  2.2856E+01
287  1.4300E-03 -1.4044E+00  7.0549E+01 -6.0813E+00 -1.6461E+00  7.3724E+01  2.2264E+01
289  1.4400E-03 -1.4018E+00  7.1110E+01 -6.3920E+00 -1.6652E+00  7.4433E+01  2.1652E+01
291  1.4500E-03 -1.3987E+00  7.1664E+01 -6.6982E+00 -1.6832E+00  7.5118E+01  2.1018E+01
293  1.4600E-03 -1.3956E+00  7.2220E+01 -7.0021E+00 -1.6999E+00  7.5779E+01  2.0363E+01
295  1.4700E-03 -1.3921E+00  7.2780E+01 -7.3024E+00 -1.7154E+00  7.6414E+01  1.9688E+01
297  1.4800E-03 -1.3884E+00  7.3338E+01 -7.5999E+00 -1.7295E+00  7.7023E+01  1.8994E+01
299  1.4900E-03 -1.3844E+00  7.3892E+01 -7.8941E+00 -1.7421E+00  7.7605E+01  1.8280E+01
301  1.5000E-03 -1.3801E+00  7.4440E+01 -8.1850E+00 -1.7533E+00  7.8161E+01  1.7546E+01
```

(This history is abbreviated for illustrative purposes.)

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E.   INTEGRATION USING SIMPS1

The final step in the ELSHOK analysis of Case I is to
use an appropriate integration algorithm to calculate a
deflection history from the velocity information provided
by the USLOB code. Simpson's 1/3 rule was chosen in this
work and in this example, implemented in the form of
SIMPS1.BAS which appears in appendix B.

The following is an entire output listing from this
program. In the listing, the coordinate directions are
defined as:

X = fore and aft
Y = vertical or normal to the hull
Z = athwartships

```
T =   0.0100  nsec   DX =   0.000000  in.   DY =   0.000000  in.   DZ = -0.000002
T =   0.0300  nsec   DX =   0.000000  in.   DY =   0.000001  in.   DZ = -0.000014
T =   0.0500  nsec   DX =   0.000001  in.   DY =   0.000001  in.   DZ = -0.000040
T =   0.0700  nsec   DX =   0.000002  in.   DY =   0.000000  in.   DZ = -0.000083
T =   0.0900  nsec   DX =   0.000004  in.   DY = -0.000004  in.   DZ = -0.000144
T =   0.1100  nsec   DX =   0.000006  in.   DY = -0.000012  in.   DZ = -0.000223
T =   0.1300  nsec   DX =   0.000009  in.   DY = -0.000026  in.   DZ = -0.000322
T =   0.1500  nsec   DX =   0.000013  in.   DY = -0.000047  in.   DZ = -0.000441
T =   0.1700  nsec   DX =   0.000018  in.   DY = -0.000075  in.   DZ = -0.000581
T =   0.1900  nsec   DX =   0.000023  in.   DY = -0.000112  in.   DZ = -0.000741
T =   0.2100  nsec   DX =   0.000029  in.   DY = -0.000157  in.   DZ = -0.000920
T =   0.2300  nsec   DX =   0.000036  in.   DY = -0.000210  in.   DZ = -0.001116
T =   0.2500  nsec   DX =   0.000043  in.   DY = -0.000271  in.   DZ = -0.001329
T =   0.2700  nsec   DX =   0.000050  in.   DY = -0.000339  in.   DZ = -0.001555
T =   0.2900  nsec   DX =   0.000056  in.   DY = -0.000414  in.   DZ = -0.001793
T =   0.3100  nsec   DX =   0.000063  in.   DY = -0.000493  in.   DZ = -0.002040
T =   0.3300  nsec   DX =   0.000069  in.   DY = -0.000577  in.   DZ = -0.002295
T =   0.3500  nsec   DX =   0.000074  in.   DY = -0.000662  in.   DZ = -0.002555
T =   0.3700  nsec   DX =   0.000079  in.   DY = -0.000748  in.   DZ = -0.002819
T =   0.3900  nsec   DX =   0.000082  in.   DY = -0.000832  in.   DZ = -0.003086
T =   0.4100  nsec   DX =   0.000084  in.   DY = -0.000913  in.   DZ = -0.003354
T =   0.4300  nsec   DX =   0.000085  in.   DY = -0.000988  in.   DZ = -0.003620
T =   0.4500  nsec   DX =   0.000085  in.   DY = -0.001057  in.   DZ = -0.003883
T =   0.4700  nsec   DX =   0.000084  in.   DY = -0.001117  in.   DZ = -0.004141
T =   0.4900  nsec   DX =   0.000081  in.   DY = -0.001167  in.   DZ = -0.004392
T =   0.5100  nsec   DX =   0.000077  in.   DY = -0.001206  in.   DZ = -0.004634
```

```
T =   0.5300  msec   DX =   0.000073  in.   DY =  -0.001233  in.   DZ =  -0.004864
T =   0.5500  msec   DX =   0.000067  in.   DY =  -0.001248  in.   DZ =  -0.005001
T =   0.5700  msec   DX =   0.000060  in.   DY =  -0.001251  in.   DZ =  -0.005283
T =   0.5900  msec   DX =   0.000053  in.   DY =  -0.001241  in.   DZ =  -0.005468
T =   0.6100  msec   DX =   0.000046  in.   DY =  -0.001219  in.   DZ =  -0.005634
T =   0.6300  msec   DX =   0.000038  in.   DY =  -0.001186  in.   DZ =  -0.005780
T =   0.6500  msec   DX =   0.000030  in.   DY =  -0.001144  in.   DZ =  -0.005903
T =   0.6700  msec   DX =   0.000021  in.   DY =  -0.001093  in.   DZ =  -0.006004
T =   0.6900  msec   DX =   0.000014  in.   DY =  -0.001035  in.   DZ =  -0.006079
T =   0.7100  msec   DX =   0.000006  in.   DY =  -0.000972  in.   DZ =  -0.006129

T =   0.7300  msec   DX =  -0.000001  in.   DY =  -0.000905  in.   DZ =  -0.006152
T =   0.7500  msec   DX =  -0.000008  in.   DY =  -0.000837  in.   DZ =  -0.006146
T =   0.7700  msec   DX =  -0.000014  in.   DY =  -0.000770  in.   DZ =  -0.006113
T =   0.7900  msec   DX =  -0.000019  in.   DY =  -0.000706  in.   DZ =  -0.006050
T =   0.8100  msec   DX =  -0.000024  in.   DY =  -0.000646  in.   DZ =  -0.005957
T =   0.8300  msec   DX =  -0.000027  in.   DY =  -0.000592  in.   DZ =  -0.005835
T =   0.8500  msec   DX =  -0.000030  in.   DY =  -0.000546  in.   DZ =  -0.005683
T =   0.8700  msec   DX =  -0.000032  in.   DY =  -0.000509  in.   DZ =  -0.005502
T =   0.8900  msec   DX =  -0.000032  in.   DY =  -0.000483  in.   DZ =  -0.005291
T =   0.9100  msec   DX =  -0.000032  in.   DY =  -0.000467  in.   DZ =  -0.005050
T =   0.9300  msec   DX =  -0.000031  in.   DY =  -0.000462  in.   DZ =  -0.004781
T =   0.9500  msec   DX =  -0.000029  in.   DY =  -0.000469  in.   DZ =  -0.004484
T =   0.9700  msec   DX =  -0.000025  in.   DY =  -0.000488  in.   DZ =  -0.004158
T =   0.9900  msec   DX =  -0.000022  in.   DY =  -0.000516  in.   DZ =  -0.003806
T =   1.0100  msec   DX =  -0.000017  in.   DY =  -0.000555  in.   DZ =  -0.003426
T =   1.0300  msec   DX =  -0.000012  in.   DY =  -0.000603  in.   DZ =  -0.003021
T =   1.0500  msec   DX =  -0.000006  in.   DY =  -0.000658  in.   DZ =  -0.002592
T =   1.0700  msec   DX =   0.000000  in.   DY =  -0.000719  in.   DZ =  -0.002141
T =   1.0900  msec   DX =   0.000006  in.   DY =  -0.000783  in.   DZ =  -0.001668
T =   1.1100  msec   DX =   0.000013  in.   DY =  -0.000850  in.   DZ =  -0.001175
T =   1.1300  msec   DX =   0.000019  in.   DY =  -0.000917  in.   DZ =  -0.000663
T =   1.1500  msec   DX =   0.000026  in.   DY =  -0.000982  in.   DZ =  -0.000135
T =   1.1700  msec   DX =   0.000032  in.   DY =  -0.001044  in.   DZ =   0.000408
T =   1.1900  msec   DX =   0.000037  in.   DY =  -0.001100  in.   DZ =   0.000965
T =   1.2100  msec   DX =   0.000043  in.   DY =  -0.001149  in.   DZ =   0.001533
T =   1.2300  msec   DX =   0.000047  in.   DY =  -0.001189  in.   DZ =   0.002111
T =   1.2500  msec   DX =   0.000051  in.   DY =  -0.001219  in.   DZ =   0.002697
T =   1.2700  msec   DX =   0.000054  in.   DY =  -0.001238  in.   DZ =   0.003298
T =   1.2900  msec   DX =   0.000056  in.   DY =  -0.001246  in.   DZ =   0.003887
T =   1.3100  msec   DX =   0.000057  in.   DY =  -0.001242  in.   DZ =   0.004486
T =   1.3300  msec   DX =   0.000057  in.   DY =  -0.001228  ...    DZ =   0.005085
T =   1.3500  msec   DX =   0.000056  in.   DY =  -0.001199  in.   DZ =   0.005682
T =   1.3700  msec   DX =   0.000054  in.   DY =  -0.001161  in.   DZ =   0.006274
T =   1.3900  msec   DX =   0.000051  in.   DY =  -0.001113  in.   DZ =   0.006868
T =   1.4100  msec   DX =   0.000047  in.   DY =  -0.001057  in.   DZ =   0.007437
T =   1.4300  msec   DX =   0.000042  in.   DY =  -0.000993  in.   DZ =   0.008004
T =   1.4500  msec   DX =   0.000037  in.   DY =  -0.000924  in.   DZ =   0.008558
T =   1.4700  msec   DX =   0.000030  in.   DY =  -0.000852  in.   DZ =   0.009099
T =   1.4900  msec   DX =   0.000023  in.   DY =  -0.000777  in.   DZ =   0.009621
T =   1.5100  msec   DX =   0.000015  in.   DY =  -0.000703  in.   DZ =   0.010127
T =   1.5300  msec   DX =   0.000007  in.   DY =  -0.000632  in.   DZ =   0.010612
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T =   1.5500  msec   DX =  -0.000001  in.   DY =  -0.000564  in.   DZ =   0.011075
T =   1.5700  msec   DX =  -0.000010  in.   DY =  -0.000503  in.   DZ =   0.011514
T =   1.5900  msec   DX =  -0.000019  in.   DY =  -0.000449  in.   DZ =   0.011927
T =   1.6100  msec   DX =  -0.000028  in.   DY =  -0.000403  in.   DZ =   0.012312
T =   1.6300  msec   DX =  -0.000036  in.   DY =  -0.000368  in.   DZ =   0.012667
T =   1.6500  msec   DX =  -0.000045  in.   DY =  -0.000344  in.   DZ =   0.012990
T =   1.6700  msec   DX =  -0.000053  in.   DY =  -0.000331  in.   DZ =   0.013282
T =   1.6900  msec   DX =  -0.000060  in.   DY =  -0.000329  in.   DZ =   0.013540
T =   1.7100  msec   DX =  -0.000067  in.   DY =  -0.000339  in.   DZ =   0.013764
T =   1.7300  msec   DX =  -0.000072  in.   DY =  -0.000359  in.   DZ =   0.013952
T =   1.7500  msec   DX =  -0.000077  in.   DY =  -0.000390  in.   DZ =   0.014104
T =   1.7700  msec   DX =  -0.000082  in.   DY =  -0.000430  in.   DZ =   0.014219
T =   1.7900  msec   DX =  -0.000085  in.   DY =  -0.000477  in.   DZ =   0.014297
T =   1.8100  msec   DX =  -0.000087  in.   DY =  -0.000531  in.   DZ =   0.014336
T =   1.8300  msec   DX =  -0.000088  in.   DY =  -0.000588  in.   DZ =   0.014337
T =   1.8500  msec   DX =  -0.000088  in.   DY =  -0.000648  in.   DZ =   0.014299
T =   1.8700  msec   DX =  -0.000087  in.   DY =  -0.000709  in.   DZ =   0.014222
T =   1.8900  msec   DX =  -0.000085  in.   DY =  -0.000769  in.   DZ =   0.014105
T =   1.9100  msec   DX =  -0.000083  in.   DY =  -0.000824  in.   DZ =   0.013950
T =   1.9300  msec   DX =  -0.000079  in.   DY =  -0.000875  in.   DZ =   0.013755
T =   1.9500  msec   DX =  -0.000075  in.   DY =  -0.000919  in.   DZ =   0.013522
T =   1.9700  msec   DX =  -0.000070  in.   DY =  -0.000954  in.   DZ =   0.013251
T =   1.9900  msec   DX =  -0.000064  in.   DY =  -0.000988  in.   DZ =   0.012943
T =   2.0100  msec   DX =  -0.000058  in.   DY =  -0.000995  in.   DZ =   0.012598
T =   2.0300  msec   DX =  -0.000051  in.   DY =  -0.000999  in.   DZ =   0.012218
T =   2.0500  msec   DX =  -0.000045  in.   DY =  -0.000991  in.   DZ =   0.011804
T =   2.0700  msec   DX =  -0.000038  in.   DY =  -0.000971  in.   DZ =   0.011355
T =   2.0900  msec   DX =  -0.000032  in.   DY =  -0.000940  in.   DZ =   0.010875
T =   2.1100  msec   DX =  -0.000025  in.   DY =  -0.000898  in.   DZ =   0.010363
T =   2.1300  msec   DX =  -0.000019  in.   DY =  -0.000846  in.   DZ =   0.009822
T =   2.1500  msec   DX =  -0.000014  in.   DY =  -0.000786  in.   DZ =   0.009252
T =   2.1700  msec   DX =  -0.000009  in.   DY =  -0.000718  in.   DZ =   0.008654
T =   2.1900  msec   DX =  -0.000005  in.   DY =  -0.000645  in.   DZ =   0.008030
T =   2.2100  msec   DX =  -0.000001  in.   DY =  -0.000568  in.   DZ =   0.007383
T =   2.2300  msec   DX =   0.000001  in.   DY =  -0.000489  in.   DZ =   0.006713
T =   2.2500  msec   DX =   0.000003  in.   DY =  -0.000410  in.   DZ =   0.006024
T =   2.2700  msec   DX =   0.000004  in.   DY =  -0.000333  in.   DZ =   0.005318
T =   2.2900  msec   DX =   0.000003  in.   DY =  -0.000260  in.   DZ =   0.004595
T =   2.3100  msec   DX =   0.000002  in.   DY =  -0.000193  in.   DZ =   0.003858
T =   2.3300  msec   DX =  -0.000000  in.   DY =  -0.000133  in.   DZ =   0.003111
T =   2.3500  msec   DX =  -0.000004  in.   DY =  -0.000082  in.   DZ =   0.002354
T =   2.3700  msec   DX =  -0.000008  in.   DY =  -0.000041  in.   DZ =   0.001589
T =   2.3900  msec   DX =  -0.000013  in.   DY =  -0.000011  in.   DZ =   0.000820
T =   2.4100  msec   DX =  -0.000019  in.   DY =   0.000007  in.   DZ =   0.000048
T =   2.4300  msec   DX =  -0.000026  in.   DY =   0.000013  in.   DZ =  -0.000724
T =   2.4500  msec   DX =  -0.000033  in.   DY =   0.000008  in.   DZ =  -0.001493
T =   2.4700  msec   DX =  -0.000041  in.   DY =  -0.000008  in.   DZ =  -0.002258
T =   2.4900  msec   DX =  -0.000049  in.   DY =  -0.000035  in.   DZ =  -0.003017
T =   2.5100  msec   DX =  -0.000057  in.   DY =  -0.000071  in.   DZ =  -0.003765
T =   2.5300  msec   DX =  -0.000065  in.   DY =  -0.000116  in.   DZ =  -0.004502
T =   2.5500  msec   DX =  -0.000074  in.   DY =  -0.000167  in.   DZ =  -0.005226
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T =   2.5700   msec   DX =  -0.000082   in.   DY =  -0.000223   in.   DZ =  -0.005933
T =   2.5900   msec   DX =  -0.000090   in.   DY =  -0.000282   in.   DZ =  -0.006623
T =   2.6100   msec   DX =  -0.000098   in.   DY =  -0.000342   in.   DZ =  -0.007294
T =   2.6300   msec   DX =  -0.000105   in.   DY =  -0.000402   in.   DZ =  -0.007942
T =   2.6500   msec   DX =  -0.000111   in.   DY =  -0.000458   in.   DZ =  -0.008566
T =   2.6700   msec   DX =  -0.000117   in.   DY =  -0.000510   in.   DZ =  -0.009166
T =   2.6900   msec   DX =  -0.000122   in.   DY =  -0.000555   in.   DZ =  -0.009739
T =   2.7100   msec   DX =  -0.000126   in.   DY =  -0.000592   in.   DZ =  -0.010281
T =   2.7300   msec   DX =  -0.000129   in.   DY =  -0.000620   in.   DZ =  -0.010794
T =   2.7500   msec   DX =  -0.000131   in.   DY =  -0.000638   in.   DZ =  -0.011274
T =   2.7700   msec   DX =  -0.000132   in.   DY =  -0.000644   in.   DZ =  -0.011720
T =   2.7900   msec   DX =  -0.000131   in.   DY =  -0.000639   in.   DZ =  -0.012133
T =   2.8100   msec   DX =  -0.000130   in.   DY =  -0.000623   in.   DZ =  -0.012510
T =   2.8300   msec   DX =  -0.000128   in.   DY =  -0.000595   in.   DZ =  -0.012850
T =   2.8500   msec   DX =  -0.000125   in.   DY =  -0.000556   in.   DZ =  -0.013155
T =   2.8700   msec   DX =  -0.000121   in.   DY =  -0.000507   in.   DZ =  -0.013421
T =   2.8900   msec   DX =  -0.000116   in.   DY =  -0.000449   in.   DZ =  -0.013648
T =   2.9100   msec   DX =  -0.000111   in.   DY =  -0.000384   in.   DZ =  -0.013837
T =   2.9300   msec   DX =  -0.000105   in.   DY =  -0.000313   in.   DZ =  -0.013987
T =   2.9500   msec   DX =  -0.000098   in.   DY =  -0.000238   in.   DZ =  -0.014097
T =   2.9700   msec   DX =  -0.000091   in.   DY =  -0.000161   in.   DZ =  -0.014166
T =   2.9900   msec   DX =  -0.000084   in.   DY =  -0.000085   in.   DZ =  -0.014196
T =   3.0100   msec   DX =  -0.000077   in.   DY =  -0.000010   in.   DZ =  -0.014185
T =   3.0300   msec   DX =  -0.000070   in.   DY =   0.000061   in.   DZ =  -0.014135
T =   3.0500   msec   DX =  -0.000063   in.   DY =   0.000126   in.   DZ =  -0.014046
T =   3.0700   msec   DX =  -0.000056   in.   DY =   0.000184   in.   DZ =  -0.013917
T =   3.0900   msec   DX =  -0.000050   in.   DY =   0.000233   in.   DZ =  -0.013751
T =   3.1100   msec   DX =  -0.000044   in.   DY =   0.000272   in.   DZ =  -0.013548
T =   3.1300   msec   DX =  -0.000039   in.   DY =   0.000299   in.   DZ =  -0.013309
T =   3.1500   msec   DX =  -0.000035   in.   DY =   0.000315   in.   DZ =  -0.013034
T =   3.1700   msec   DX =  -0.000031   in.   DY =   0.000320   in.   DZ =  -0.012726
T =   3.1900   msec   DX =  -0.000028   in.   DY =   0.000312   in.   DZ =  -0.012385
T =   3.2100   msec   DX =  -0.000027   in.   DY =   0.000294   in.   DZ =  -0.012011
T =   3.2300   msec   DX =  -0.000026   in.   DY =   0.000264   in.   DZ =  -0.011608
T =   3.2500   msec   DX =  -0.000026   in.   DY =   0.000225   in.   DZ =  -0.011176
T =   3.2700   msec   DX =  -0.000027   in.   DY =   0.000177   in.   DZ =  -0.010715
T =   3.2900   msec   DX =  -0.000030   in.   DY =   0.000123   in.   DZ =  -0.010231
T =   3.3100   msec   DX =  -0.000033   in.   DY =   0.000063   in.   DZ =  -0.009723
T =   3.3300   msec   DX =  -0.000037   in.   DY =   0.000000   in.   DZ =  -0.009192
T =   3.3500   msec   DX =  -0.000042   in.   DY =  -0.000064   in.   DZ =  -0.008642
T =   3.3700   msec   DX =  -0.000047   in.   DY =  -0.000127   in.   DZ =  -0.008076
T =   3.3900   msec   DX =  -0.000054   in.   DY =  -0.000188   in.   DZ =  -0.007492
T =   3.4100   msec   DX =  -0.000060   in.   DY =  -0.000244   in.   DZ =  -0.006897
T =   3.4300   msec   DX =  -0.000068   in.   DY =  -0.000294   in.   DZ =  -0.006298
T =   3.4500   msec   DX =  -0.000075   in.   DY =  -0.000336   in.   DZ =  -0.005673
T =   3.4700   msec   DX =  -0.000083   in.   DY =  -0.000368   in.   DZ =  -0.005050
T =   3.4900   msec   DX =  -0.000091   in.   DY =  -0.000390   in.   DZ =  -0.004422
T =   3.5100   msec   DX =  -0.000098   in.   DY =  -0.000400   in.   DZ =  -0.003791
T =   3.5300   msec   DX =  -0.000105   in.   DY =  -0.000399   in.   DZ =  -0.003159
T =   3.5500   msec   DX =  -0.000112   in.   DY =  -0.000387   in.   DZ =  -0.002530
T =   3.5700   msec   DX =  -0.000119   in.   DY =  -0.000362   in.   DZ =  -0.001905
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T =   3.5900  msec   DX =  -0.000125  in.   DY =  -0.000327  in.   DZ =  -0.001286
T =   3.6100  msec   DX =  -0.000130  in.   DY =  -0.000281  in.   DZ =  -0.000677
T =   3.6300  msec   DX =  -0.000134  in.   DY =  -0.000227  in.   DZ =  -0.000079
T =   3.6500  msec   DX =  -0.000138  in.   DY =  -0.000165  in.   DZ =   0.000508
T =   3.6700  msec   DX =  -0.000140  in.   DY =  -0.000097  in.   DZ =   0.001078
T =   3.6900  msec   DX =  -0.000142  in.   DY =  -0.000024  in.   DZ =   0.001632
T =   3.7100  msec   DX =  -0.000142  in.   DY =   0.000050  in.   DZ =   0.002167
T =   3.7300  msec   DX =  -0.000142  in.   DY =   0.000125  in.   DZ =   0.002681
T =   3.7500  msec   DX =  -0.000140  in.   DY =   0.000197  in.   DZ =   0.003174
T =   3.7700  msec   DX =  -0.000137  in.   DY =   0.000266  in.   DZ =   0.003643
T =   3.7900  msec   DX =  -0.000134  in.   DY =   0.000330  in.   DZ =   0.004086
T =   3.8100  msec   DX =  -0.000130  in.   DY =   0.000387  in.   DZ =   0.004501
T =   3.8300  msec   DX =  -0.000124  in.   DY =   0.000434  in.   DZ =   0.004889
T =   3.8500  msec   DX =  -0.000118  in.   DY =   0.000472  in.   DZ =   0.005246
T =   3.8700  msec   DX =  -0.000112  in.   DY =   0.000499  in.   DZ =   0.005571
T =   3.8900  msec   DX =  -0.000105  in.   DY =   0.000514  in.   DZ =   0.005865
T =   3.9100  msec   DX =  -0.000097  in.   DY =   0.000518  in.   DZ =   0.006125
T =   3.9300  msec   DX =  -0.000089  in.   DY =   0.000509  in.   DZ =   0.006351
T =   3.9500  msec   DX =  -0.000081  in.   DY =   0.000489  in.   DZ =   0.006543
T =   3.9700  msec   DX =  -0.000073  in.   DY =   0.000458  in.   DZ =   0.006699
T =   3.9900  msec   DX =  -0.000065  in.   DY =   0.000418  in.   DZ =   0.006819
T =   4.0100  msec   DX =  -0.000058  in.   DY =   0.000369  in.   DZ =   0.006905
T =   4.0300  msec   DX =  -0.000051  in.   DY =   0.000313  in.   DZ =   0.006953
T =   4.0500  msec   DX =  -0.000044  in.   DY =   0.000252  in.   DZ =   0.006966
T =   4.0700  msec   DX =  -0.000038  in.   DY =   0.000187  in.   DZ =   0.006944
T =   4.0900  msec   DX =  -0.000032  in.   DY =   0.000121  in.   DZ =   0.006884
T =   4.1100  msec   DX =  -0.000028  in.   DY =   0.000056  in.   DZ =   0.006789
T =   4.1300  msec   DX =  -0.000024  in.   DY =  -0.000007  in.   DZ =   0.006659
T =   4.1500  msec   DX =  -0.000021  in.   DY =  -0.000065  in.   DZ =   0.006494
T =   4.1700  msec   DX =  -0.000020  in.   DY =  -0.000118  in.   DZ =   0.006294
T =   4.1900  msec   DX =  -0.000019  in.   DY =  -0.000162  in.   DZ =   0.006062
T =   4.2100  msec   DX =  -0.000019  in.   DY =  -0.000197  in.   DZ =   0.005796
T =   4.2300  msec   DX =  -0.000020  in.   DY =  -0.000222  in.   DZ =   0.005500
T =   4.2500  msec   DX =  -0.000022  in.   DY =  -0.000236  in.   DZ =   0.005174
T =   4.2700  msec   DX =  -0.000025  in.   DY =  -0.000238  in.   DZ =   0.004818
T =   4.2900  msec   DX =  -0.000029  in.   DY =  -0.000228  in.   DZ =   0.004436
T =   4.3100  msec   DX =  -0.000034  in.   DY =  -0.000207  in.   DZ =   0.004027
T =   4.3300  msec   DX =  -0.000039  in.   DY =  -0.000175  in.   DZ =   0.003593
T =   4.3500  msec   DX =  -0.000045  in.   DY =  -0.000132  in.   DZ =   0.003135
T =   4.3700  msec   DX =  -0.000052  in.   DY =  -0.000081  in.   DZ =   0.002657
T =   4.3900  msec   DX =  -0.000058  in.   DY =  -0.000021  in.   DZ =   0.002158
T =   4.4100  msec   DX =  -0.000065  in.   DY =   0.000044  in.   DZ =   0.001641
T =   4.4300  msec   DX =  -0.000072  in.   DY =   0.000114  in.   DZ =   0.001109
T =   4.4500  msec   DX =  -0.000079  in.   DY =   0.000187  in.   DZ =   0.000562
T =   4.4700  msec   DX =  -0.000086  in.   DY =   0.000260  in.   DZ =   0.000005
T =   4.4900  msec   DX =  -0.000093  in.   DY =   0.000331  in.   DZ =  -0.000563
T =   4.5100  msec   DX =  -0.000099  in.   DY =   0.000399  in.   DZ =  -0.001138
T =   4.5300  msec   DX =  -0.000104  in.   DY =   0.000462  in.   DZ =  -0.001719
T =   4.5500  msec   DX =  -0.000109  in.   DY =   0.000517  in.   DZ =  -0.002303
T =   4.5700  msec   DX =  -0.000113  in.   DY =   0.000565  in.   DZ =  -0.002888
T =   4.5900  msec   DX =  -0.000116  in.   DY =   0.000602  in.   DZ =  -0.003472
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T =   4.6100   msec   DX =  -0.000118  in.   DY =   0.000629  in.   DZ =  -0.004053
T =   4.6300   msec   DX =  -0.000119  in.   DY =   0.000644  in.   DZ =  -0.004629
T =   4.6500   msec   DX =  -0.000120  in.   DY =   0.000648  in.   DZ =  -0.005196
T =   4.6700   msec   DX =  -0.000119  in.   DY =   0.000648  in.   DZ =  -0.005754
T =   4.6900   msec   DX =  -0.000117  in.   DY =   0.000620  in.   DZ =  -0.006299
T =   4.7100   msec   DX =  -0.000114  in.   DY =   0.000598  in.   DZ =  -0.006831
T =   4.7300   msec   DX =  -0.000110  in.   DY =   0.000550  in.   DZ =  -0.007345
T =   4.7500   msec   DX =  -0.000105  in.   DY =   0.000501  in.   DZ =  -0.007841
T =   4.7700   msec   DX =  -0.000100  in.   DY =   0.000445  in.   DZ =  -0.008318
T =   4.7900   msec   DX =  -0.000093  in.   DY =   0.000383  in.   DZ =  -0.008772
T =   4.8100   msec   DX =  -0.000086  in.   DY =   0.000318  in.   DZ =  -0.009202
T =   4.8300   msec   DX =  -0.000079  in.   DY =   0.000251  in.   DZ =  -0.009608
T =   4.8500   msec   DX =  -0.000071  in.   DY =   0.000184  in.   DZ =  -0.009987
T =   4.8700   msec   DX =  -0.000062  in.   DY =   0.000120  in.   DZ =  -0.010337
T =   4.8900   msec   DX =  -0.000054  in.   DY =   0.000060  in.   DZ =  -0.010658
T =   4.9100   msec   DX =  -0.000045  in.   DY =   0.000005  in.   DZ =  -0.010948
T =   4.9300   msec   DX =  -0.000037  in.   DY =  -0.000042  in.   DZ =  -0.011205
T =   4.9500   msec   DX =  -0.000028  in.   DY =  -0.000079  in.   DZ =  -0.011429
T =   4.9700   msec   DX =  -0.000020  in.   DY =  -0.000107  in.   DZ =  -0.011618
T =   4.9900   msec   DX =  -0.000013  in.   DY =  -0.000124  in.   DZ =  -0.011771
T =   5.0100   msec   DX =  -0.000006  in.   DY =  -0.000129  in.   DZ =  -0.011888
T =   5.0300   msec   DX =   0.000000  in.   DY =  -0.000123  in.   DZ =  -0.011969
T =   5.0500   msec   DX =   0.000006  in.   DY =  -0.000105  in.   DZ =  -0.012012
T =   5.0700   msec   DX =   0.000011  in.   DY =  -0.000076  in.   DZ =  -0.012017
T =   5.0900   msec   DX =   0.000014  in.   DY =  -0.000037  in.   DZ =  -0.011985
T =   5.1100   msec   DX =   0.000017  in.   DY =   0.000012  in.   DZ =  -0.011914
T =   5.1300   msec   DX =   0.000019  in.   DY =   0.001498  in.   DZ =  -0.011806
T =   5.1500   msec   DX =   0.000019  in.   DY =   0.001561  in.   DZ =  -0.011659
T =   5.1700   msec   DX =   0.000019  in.   DY =   0.001629  in.   DZ =  -0.011474
T =   5.1900   msec   DX =   0.000018  in.   DY =   0.001700  in.   DZ =  -0.011252
T =   5.2100   msec   DX =   0.000016  in.   DY =   0.001771  in.   DZ =  -0.010992
T =   5.2300   msec   DX =   0.000013  in.   DY =   0.001842  in.   DZ =  -0.010696
T =   5.2500   msec   DX =   0.000009  in.   DY =   0.001909  in.   DZ =  -0.010363
T =   5.2700   msec   DX =   0.000004  in.   DY =   0.001971  in.   DZ =  -0.009996
T =   5.2900   msec   DX =  -0.000001  in.   DY =   0.002027  in.   DZ =  -0.009594
T =   5.3100   msec   DX =  -0.000007  in.   DY =   0.002074  in.   DZ =  -0.009160
T =   5.3300   msec   DX =  -0.000013  in.   DY =   0.002112  in.   DZ =  -0.008694
T =   5.3500   msec   DX =  -0.000019  in.   DY =   0.002139  in.   DZ =  -0.008198
T =   5.3700   msec   DX =  -0.000026  in.   DY =   0.002155  in.   DZ =  -0.007674
T =   5.3900   msec   DX =  -0.000032  in.   DY =   0.002160  in.   DZ =  -0.007122
T =   5.4100   msec   DX =  -0.000038  in.   DY =   0.002152  in.   DZ =  -0.006544
T =   5.4300   msec   DX =  -0.000044  in.   DY =   0.002133  in.   DZ =  -0.005943
T =   5.4500   msec   DX =  -0.000050  in.   DY =   0.002104  in.   DZ =  -0.005318
T =   5.4700   msec   DX =  -0.000055  in.   DY =   0.002064  in.   DZ =  -0.004674
T =   5.4900   msec   DX =  -0.000059  in.   DY =   0.002015  in.   DZ =  -0.004010
T =   5.5100   msec   DX =  -0.000063  in.   DY =   0.001959  in.   DZ =  -0.003329
T =   5.5300   msec   DX =  -0.000066  in.   DY =   0.001898  in.   DZ =  -0.002634
T =   5.5500   msec   DX =  -0.000068  in.   DY =   0.001832  in.   DZ =  -0.001927
T =   5.5700   msec   DX =  -0.000069  in.   DY =   0.001764  in.   DZ =  -0.001209
T =   5.5900   msec   DX =  -0.000069  in.   DY =   0.001696  in.   DZ =  -0.000483
T =   5.6100   msec   DX =  -0.000068  in.   DY =   0.001630  in.   DZ =   0.000248
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T =    5.6300   msec    DX =  -0.000066  in.    DY =   0.001567  in.    DZ =   0.000983
T =    5.6500   msec    DX =  -0.000063  in.    DY =   0.001510  in.    DZ =   0.001720
T =    5.6700   msec    DX =  -0.000059  in.    DY =   0.001461  in.    DZ =   0.002456
T =    5.6900   msec    DX =  -0.000054  in.    DY =   0.001428  in.    DZ =   0.003189
T =    5.7100   msec    DX =  -0.000049  in.    DY =   0.001389  in.    DZ =   0.003917
T =    5.7300   msec    DX =  -0.000042  in.    DY =   0.001369  in.    DZ =   0.004638
T =    5.7500   msec    DX =  -0.000035  in.    DY =   0.001360  in.    DZ =   0.005350
T =    5.7700   msec    DX =  -0.000027  in.    DY =   0.001363  in.    DZ =   0.006051
T =    5.7900   msec    DX =  -0.000019  in.    DY =   0.001377  in.    DZ =   0.006737
T =    5.8100   msec    DX =  -0.000010  in.    DY =   0.001403  in.    DZ =   0.007408
T =    5.8300   msec    DX =  -0.000001  in.    DY =   0.001439  in.    DZ =   0.008061
T =    5.8500   msec    DX =   0.000008  in.    DY =   0.001485  in.    DZ =   0.008694
T =    5.8700   msec    DX =   0.000017  in.    DY =   0.001539  in.    DZ =   0.009305
T =    5.8900   msec    DX =   0.000025  in.    DY =   0.001599  in.    DZ =   0.009892
T =    5.9100   msec    DX =   0.000034  in.    DY =   0.001665  in.    DZ =   0.010454
T =    5.9300   msec    DX =   0.000042  in.    DY =   0.001734  in.    DZ =   0.010990
T =    5.9500   msec    DX =   0.000049  in.    DY =   0.001804  in.    DZ =   0.011497
T =    5.9700   msec    DX =   0.000056  in.    DY =   0.001873  in.    DZ =   0.011974
T =    5.9900   msec    DX =   0.000062  in.    DY =   0.001939  in.    DZ =   0.012420
TMAX(X) =   3.7100    msec  DMAX(X) =  -0.000142    in.
TMAX(Y) =   5.3900    msec  DMAX(Y) =   0.002160    in.
TMAX(Z) =   1.8300    msec  DMAX(Z) =   0.014337    in.
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